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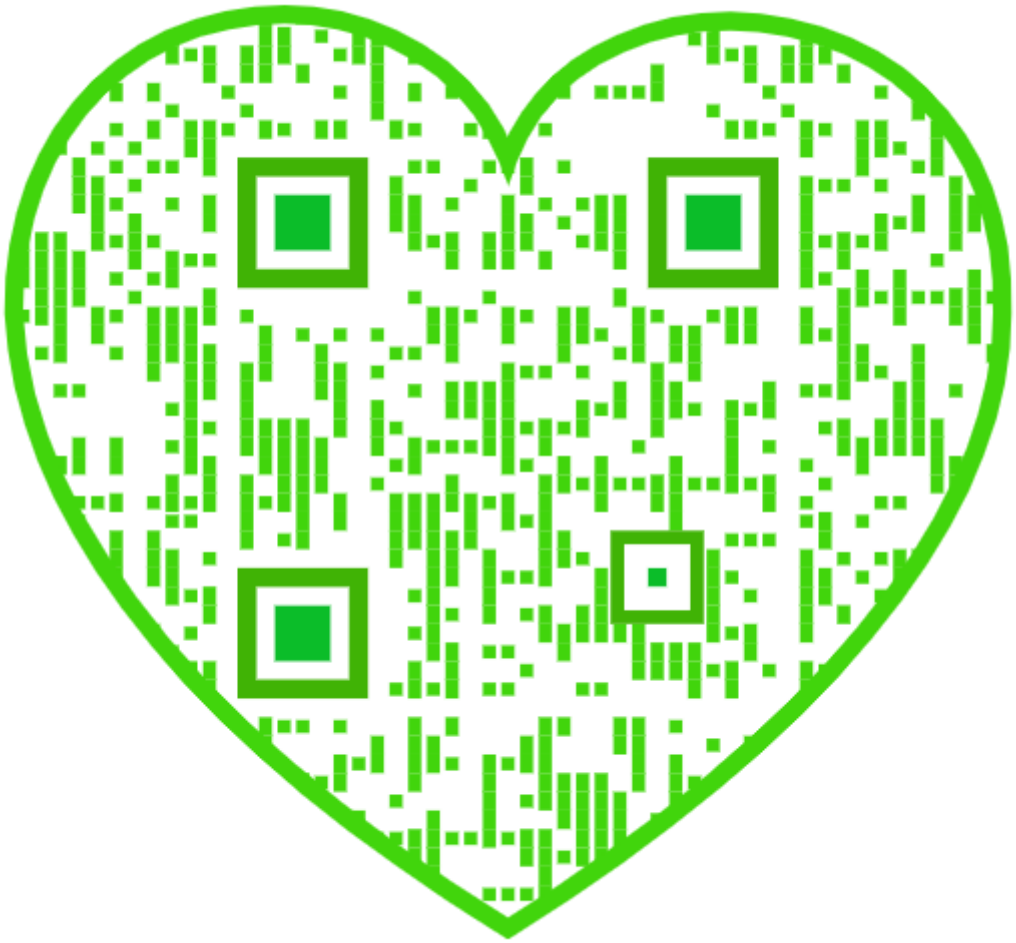

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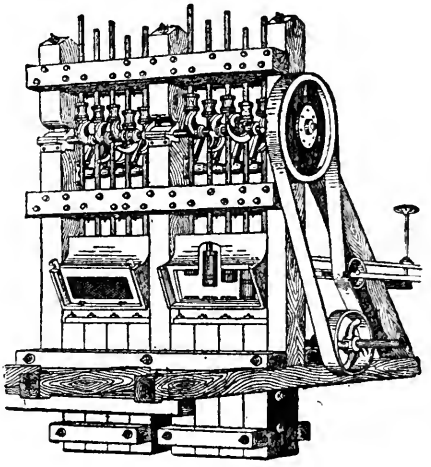

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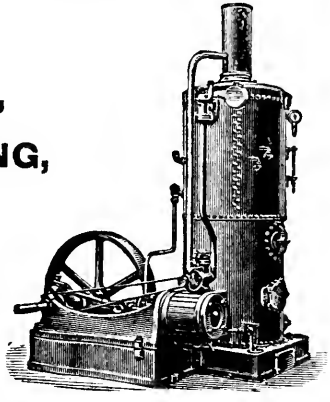

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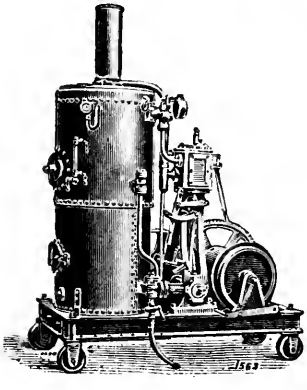

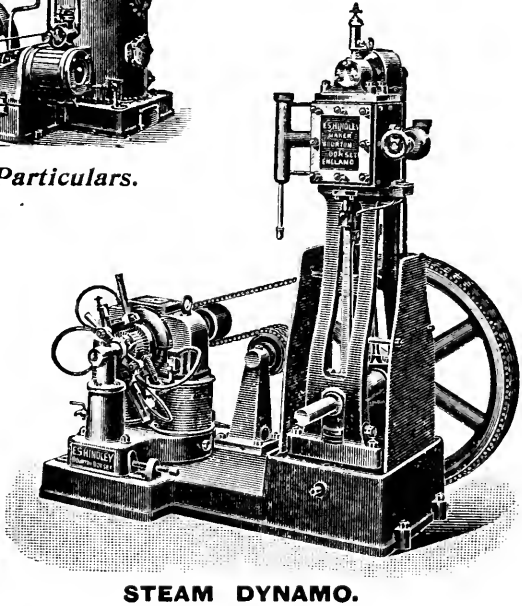

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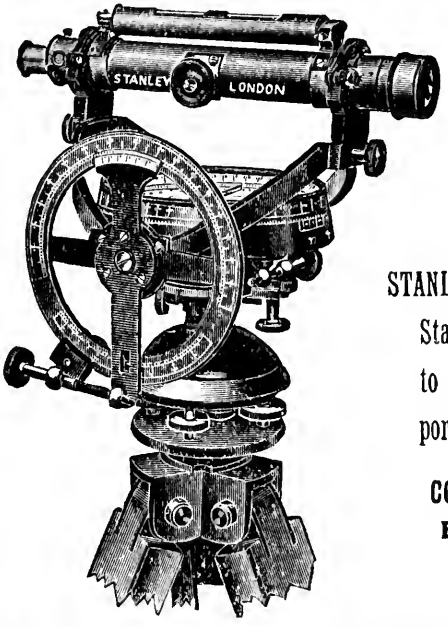

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BY

E. HENRY DAVIES, F.G.S.

MINING ENGINEER

MEMBER OF THE INSTITUTION OF MINING AND METALLURGY AND
OF THE AMERICAN INSTITUTE OF MINING ENGINEERS

SECOND EDITION, REWRITTEN AND ENLARGED

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PREFACE TO THE FIRST EDITION.

THE continued favour awarded to the mining works of my father, the late Mr. D. C. DAVIES, F.G.S., coupled with the recent advances and improvements in mining machinery, has created a demand for a more comprehensive and detailed description of the Machinery used in Metalliferous Mines than was permissible in the few chapters devoted to that subject in my father's work on METALLIFEROUS MINES AND MINING, the Fifth edition of which, revised and enlarged by myself, has recently been published.

The present work, therefore, is designed as a companion volume to the former, and is devoted exclusively to the description of the various machines in daily successful use in mining, both for the extraction and transport of the ore, and for its concentration and preparation for the market. It does not deal with the occurrence of mineral lodes, nor does it attempt to exhaust the list of the numberless new processes and new patents which the fertile brains of inventors are almost daily bringing before the public, only too often to attract a brief attention and never to come into practical use.

My endeavour has been to lay before my readers such a review of practical mining machinery as will enable them to appreciate for themselves the merits of the various machines; and while I have drawn largely upon my own experience, I have taken pains to supplement this, where necessary, by availing myself of the

best sources of information. In particular, I must thank my friend, Mr. Philip Argall, M.E., of Denver, Colorado, U.S.A., to whom are largely due the chapters in which Pumping Machinery is dealt with; and I have also to express my obligations to the various authors to whose works reference is made, as well as to Messrs. Fraser & Chalmers and other makers of machinery, for their assistance.

London, 1894.

PREFACE TO THE SECOND EDITION.

THE preparation of the Second edition of this work has been a source of pleasure to me, not only because the demand for a new impression affords such gratifying evidence of the interest taken in the First edition, but also because it has given me the opportunity of bringing the work up to date.

In doing this I have eliminated not a little matter that has passed out of general practice, even in the few years which have elapsed since the First edition was issued, and have added new matter to take its place.

I have endeavoured as far as possible to draw upon my own experience in Mining and Concentration, as well as in the application of Electricity as a motive power for Mining Machinery, in the hope that my readers will benefit from the information thus derived from the actual practice of my profession.

I should add that I am again indebted to my friend, Mr. Philip Argall, of Denver, U.S.A., as well as to Mr. B. Nogara, of Belbano, Italy, for much valuable information relative to Dry Crushing and the use of Electric Power, for which I desire to thank them.

6, GREAT WINCHESTER STREET, LONDON, E.C.
May, 1902.

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MACHINERY

FOR

METALLIFEROUS MINES.

CHAPTER I.

WATER AS A MOTIVE POWER.

The Overshot Wheel—Construction—Sizes and Power—The Undershot Wheel—The Poncelet Wheel—Description—Turbines—The Fromont—Details of Construction—The Vortex Turbine—Details—Power Tests—Erection—The Pelton Waterwheel—Description—Standard Dimensions—Reversible and Hoisting Wheels—Governing Arrangement—Use in Electric Installations—Price and Power—Directions for Erection—Memoranda Relative to Water—The Measurement of Water—Miner's Inch Measurement—Flow of Water in Pipes and Streams—Calculation of Power from Water—Useful Hydraulic Memoranda.

Waterwheels.—The oldest known form of utilising water as a motive power is by means of a waterwheel. Waterwheels may be divided into two general classes: overshot and undershot.

In the overshot wheel the water is applied at or near the summit, and flowing into the buckets acts by its weight alone in turning the wheel. All impulse should be avoided, and the water must flow with the same velocity as the circumference of the wheel, or just so much in excess as will prevent the buckets from striking the water as they present themselves to be filled.

In the undershot wheel the impulse of the water striking the floats drives the wheel, but the effect produced is only about half of that of the overshot wheel.

Overshot Waterwheels.—The overshot wheel is made of all diameters up to and sometimes exceeding 50 ft.; but when such a head of water is available, it is advisable to use a turbine or Pelton wheel, which is much less cumbrous and more manageable than a waterwheel.

The water course may still strike the wheel either at the summit

or at a point 45 degrees from the perpendicular, in which case the wheel is termed "high breast." In the best constructed wheels the water is laid on in a thin sheet of no greater depth than will give it a somewhat greater velocity than that of the wheel, the difference being just sufficient to pour into the succeeding buckets the proper supply of water. The buckets should be so capacious that they need not be full when the wheel carries its maximum load, in order that no water may be wasted, and that they may retain the water in them to the last moment that its weight on the wheel is effective, and yet empty themselves as soon as it ceases to be so. The sheet of water should not be so broad as the wheel, so as to allow a space of about 2 in. at each side for the escape of the air from the buckets; and the velocity of the water should be somewhat greater than that of the circumference of the wheel, varying from $3\frac{1}{2}$ ft. per second for a 50-ft. wheel, up to 5 ft. per second for a 30-ft. wheel, and 7 ft. per second for a 5-ft. wheel.

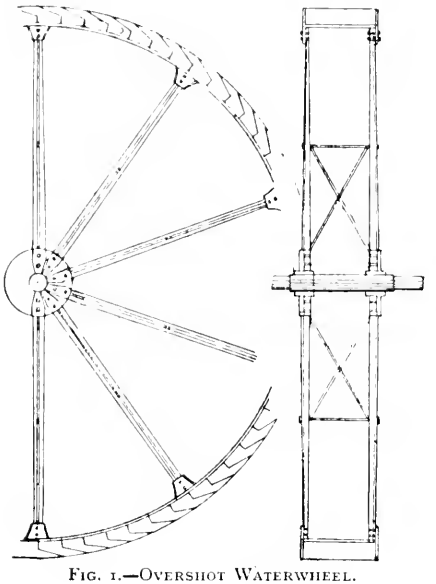


FIG. 1.—OVERSHOT WATERWHEEL.

The usual construction of the wheel is shown in fig. 1. The arms, which may be of iron or wood, are bolted to two cast iron plates fitted upon the axle. The buckets, which are made either of wood or iron, of the shape shown in fig. 2, are bolted between two shrouding plates, and are sometimes made on the ventilating system, as illustrated in fig. 3, which allows the air to make way for the ingress of the water.

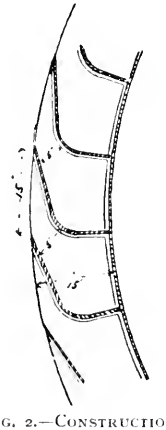


FIG. 2.—CONSTRUCTION OF BUCKETS.

FIG. 3.—VENTILATING BUCKETS.

Owing to the slow motion of the wheel, it may be connected direct to the axle of the roller crushers. For other purposes it is most convenient to multiply the speed by means of a spur-wheel attached to the arms near the periphery which

drives a pinion at about ten times the number of revolutions of the wheel itself. By this arrangement the weight of the water is brought to bear at once on the pinion teeth, and the axle becomes as it were merely a pivot on which the wheel turns, thus allowing the arms and axle to be of considerably lighter construction. In other cases, the axle of the wheel is prolonged, and carries a spur-wheel which gears into a pinion on the inside of the mill.

In ordering a waterwheel of this class full details as to the quantity of water available, the total height of the fall from the level of the supply trough to the level of the tail-race, the actual horse-power required, and the nature of the machinery to be driven, together with a plan and section of the ground, should be furnished.

The following is a list of some of the standard sizes of overshot waterwheels, together with their horse-power and the quantity of water used :—

No.	H.-P.	Head.	Diameter of Wheel.	Width of Wheel.	No. of Revolutions of Wheel.	Cubic Feet of Water per Minute.
		ft. in.	ft.	ft. in.		
1	6	8 6	8	4 0	18·3	640
2	6	11 0	10	3 0	12·3	455
3	6	13 0	12	2 9	10·5	390
4	10	11 0	10	4 6	12·3	800
5	10	16 0	15	3 6	7·9	530
6	10	21 6	20	2 6	5·5	375
7	15	16 0	15	4 6	7·9	775
8	15	21 6	20	3 6	5·5	590
9	15	26 9	25	3 0	4·4	500
10	20	21 6	20	4 6	5·5	750
11	20	26 9	25	3 9	4·4	550
12	20	31 9	30	3 0	3·1	520
13	25	26 9	25	4 6	4·4	775
14	25	31 9	30	3 9	3·1	640
15	30	26 9	25	5 0	4·4	940
16	30	31 9	30	4 3	3·1	760
17	35	26 9	25	5 9	4·6	1130
18	35	31 9	30	5 0	3·1	920
19	40	26 9	25	6 3	3·1	1250
20	40	31 9	30	5 6	3·1	1030

Undershot Waterwheels.—The most effective form of undershot waterwheel is that known as the Poncelet, which will develop 60 per cent. of the energy of the water, in comparison with the 30 per cent. obtained from the ordinary form.

This type of wheel is especially suited for falls of under 8 ft., where the quantity of water is large, as by this mode of working the wheel from below it is not subjected to a load of water, but receives it as it were under pressure.* This wheel can consequently be made very light,

* "Rudimentary Treatise on the Power of Water," by J. Glynn, F.R.S. (Weale's Series.) London : Crosby Lockwood & Son.

although of great power, with arms of wrought iron, like the paddle-wheels of a steamer; and as it can be driven at a greater rate than the breast-wheel, a larger quantity of water may be brought to bear upon a narrower wheel. It is fitted with curved buckets, deeper than those of a breast-wheel, and without backs or roll boards, so that within the rim of the wheel they are altogether open, and as the air can offer no impediment to the water's entrance or exit, the buckets are more numerous and their mouths narrower; one great object in this design being to make the action of the water continuous, avoiding the shock experienced in the undershot wheel; the water enters them nearly at the lowest point of the wheel, and at a tangent to it, issuing from beneath a curved sluice, which is opened by being drawn upwards by ranks and pinions, as shown in fig. 4.

This sluice is nearly in contact with the wheel, so that the broad

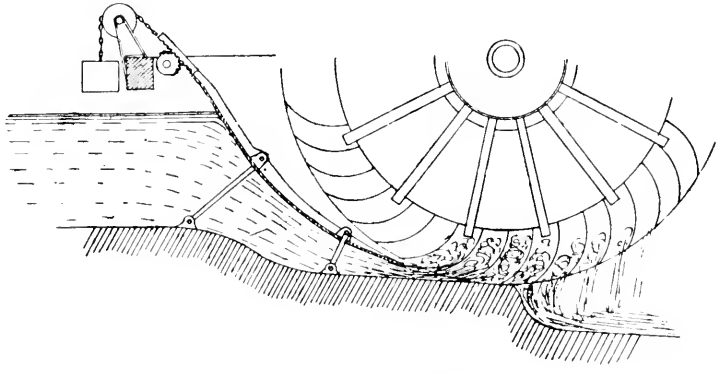


Fig. 4.—Poncelet's Undershot Waterwheel.

stream of water acts directly upon the buckets with all the pressure due to the head; and as they present themselves in rapid succession, this pressure is almost constant. The sluice is placed in an inclined position, leaning as it were against the water, and is held down by radius bars extending from the back of it to the masonry below; these bars serve not only to retain the sluice in its proper place, but to guide it as it opens or shuts down upon the sill.

A wheel on this system 16 ft. 8 in. diameter, and 30 ft. wide, driven by a fall of water 6 ft. 6 in. high, yielding 120,000 cubic ft. per minute, developed 180 horse-power, when the circumference moved at the rate of 11 ft. to 12 ft. per second. An ordinary breast-wheel would have to be 90 ft. wide in order to give the same power under the same conditions, so that the Poncelet system is generally acknowledged to the best undershot wheels.

The Working of Waterwheels.—Although an apparently simple form of machine, the overshot waterwheel requires a certain amount of attention,

especially at the time of starting; and I speak from an experience of wheels of this type up to 55 ft. in diameter.

In most old-fashioned concentration mills it was customary to fix the waterwheel direct on to the shaft of the roller crusher, as shown in fig. 153 (page 237) Now, in starting a wheel, if the water is allowed to run on without control a smash is certain to occur. The one side of the wheel becomes fully loaded with water, and immediately its load exceeds that of the friction offered by the machinery attached the wheel will spin around. Unless the flow of water is immediately checked some portion of the wheel or gearing will break. The water must therefore be kept under control until the wheel has settled to its regular speed, which for large wheels is only from 4 to 6 revolutions per minute. The wheel should always be carefully housed in, both in order to keep the water from spraying about and also as a protection from the frost and wind. The use of waterwheels of large diameter is now practically abandoned in favour of turbines, and, as I have had a large experience of both, my opinion is strongly in favour of the latter for all purposes as being far more efficient and much easier to control.

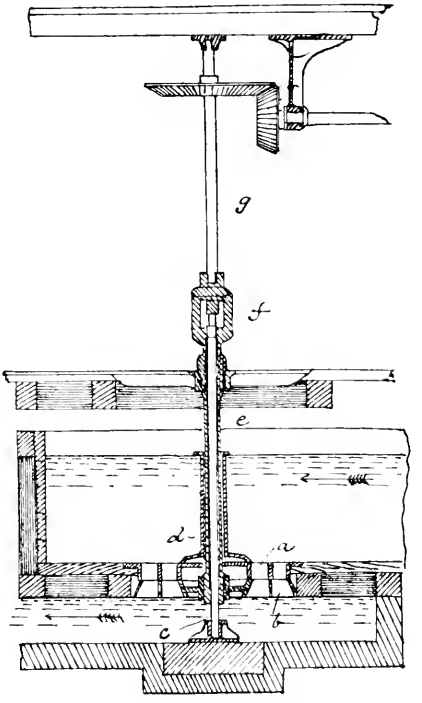


Fig. 5.—The Fromont Turbine.

Turbines.—The use of waterwheels for mining purposes is being gradually superseded by that of turbines, the latter being usually adopted for milling work in preference to the old-fashioned wheel.

This is due not only to the higher percentage of useful effect obtained, which, if the theoretical power is put at 1·00, is equal to ·75 as compared with ·68 in the best constructed overshot wheel, but also to their compactness and portability and the ease with which they can be controlled.

In the south of France a very simple and effective form of turbine, connected with the name of M. Fromont, is much in use; and, as I have erected one for the purpose of driving a large lead concentrating mill, I propose first of all to describe it. The wheel consists of two

parts (fig. 6). The upper one (*a*) is fixed, and is provided with a strong flange, by means of which it is secured to the bottom of a cistern or tank, and beneath this is the revolving wheel (*b*) keyed on to a vertical sleeve, slipped over the shaft (*c*) shown also in the sectional elevation of the complete mill (fig. 5.)

The fixed wheel (*a*) was 8 ft. in diameter, and was provided with a strong cast iron pipe (*c*) about a foot in diameter, and rising above the highest level of the flood-water.

The sleeve (*e*) to which the revolving wheel is keyed, turns in suitable bearings, and is supported on the head of the vertical shaft (*c*), as shown at *f*, in such a manner that the bearing which receives the weight and thrust of the wheel can readily be got at for oiling and adjusting.

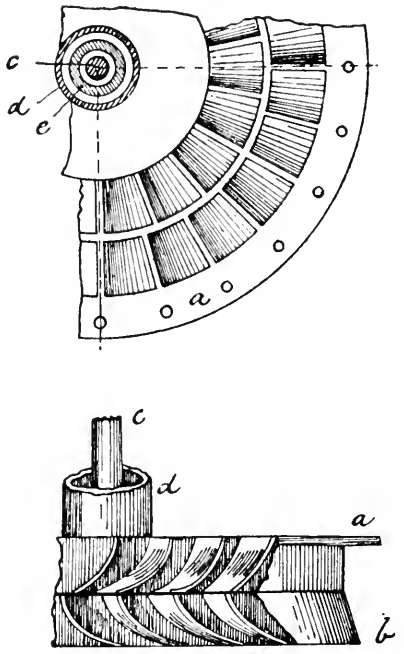


Fig. 6.—Half Plan and Section of the Fromont Turbine.

Above this point the sleeve is coupled to the vertical shaft (*g*) at the head of which the crown wheel gears in with the pinion on the end of the main shaft of the mill.

In the fixed wheel (*a*) there were forty-two openings disposed in concentric circles; the outer circle having twenty-four and the inner circle eighteen. These openings radiated from the centre of the wheel and were formed, as shown in the section, to direct the water into the buckets of the revolving wheel below it. The shape of the buckets in both wheels is clearly shown in the section, and their arrangement in the plan (fig. 6). The wheel was controlled by means of sluices in the canal leading to the turbine chamber, but can be arranged so as to govern its own speed, which was 80 revolutions per minute.

The head of water at the summer level of the river was 1 m. 40, say 4ft. 6 in., and the quantity was unlimited. The nominal horse-power was 50, but the actual was nearer 80. During flood times the head was diminished and sometimes completely annulled, rendering the turbine useless. For nine months in the year, however, the wheel worked most satisfactorily, and never caused any trouble. The crown wheel was fitted with wooden teeth, and these had occasionally to be renewed.

Wheels of this type are largely used in France for driving flour, spinning, rolling, and lead-dressing mills, and their extreme simplicity and great efficiency have made them very popular.

Turbines placed horizontally on the Fromont system, shown in fig. 6, can only be used for low falls as it is evident that there is a limit to the length of the vertical shaft. For high falls of, say, over 15 ft. the water is brought in pipes under pressure to the turbine, which is fitted in an enclosed case and has its shaft horizontal with a pulley or a clutch coupling for connection either direct or by letting to the machinery to be driven. The manner of connection depends upon the speed at which the turbine and the machines connected run. High-speed dynamos can be coupled direct, but lines of shafting, as in a concentration mill, which run at a speed of from 90 to 100 revolutions per minute, require belting and probably reduction pulleys to reduce the speed of the turbine—say, 400 revolutions—down to that of the shafting.

The Vortex Turbine.—As I have had practical and very satisfactory experience with this turbine, manufactured by Messrs. Gilbert Gilkes & Co., of Kendal, I propose to use it as illustrating the construction of a turbine of the modern type, and the following description of its interior arrangements and method of governing will also be applicable to the 420 horse-power turbine built for me by Messrs. Escher Wyss & Co., of Zurich (shown in fig. 316, page 489), which drives a generating dynamo. One of the great advantages of a pressure turbine is that it can be placed at any height not exceeding 25 ft. above the outflowing water level and is therefore only affected by floods to the extent to which the flood-water rises, and this would rarely if ever exceed the length of the 25 ft. of suction pipe below the axle of the turbine.

The internal arrangement of the vortex is shown in fig. 7. The water enters the outside casing at the top, or in any other convenient position, as at the side, as in fig. 8 (Plate I.), which shows the full arrangement for the erection of a 120 horse-power turbine (see *post*, p. 12). Passing from the inflow the water is directed by means of four or more guide-blades on to the outer circumference of the revolving wheel which is driven at a velocity depending on the height of the fall. The special form of this wheel is shown in figs. 9 and 10. Having expended its energy in giving motion to the wheel, the water is discharged through two central openings half the amount being carried away by each of the suction pipes which are afterwards joined together by a breeches piece into one pipe, as seen in Plate I.

The guide-blades are movable and turn about on a pivot placed near their inner ends. These pivots extend outwards through the case, and are each provided with a crank, as in Plate I. These cranks are all connected together and are moved simultaneously either by

means of a hand-wheel or by a regulating governor as in figs. 7-10A and 309.

The turbine is provided with an ordinary sluice valve between the case and the pipe line, and once this is open the turbine either regulates its own speed by means of the governor, or is controlled by the hand-wheel attached to the interior guide-blades.

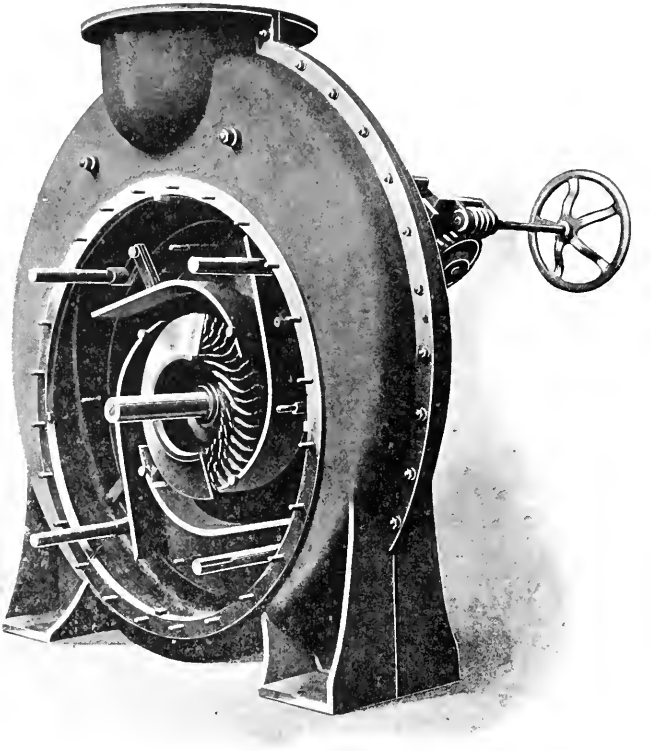
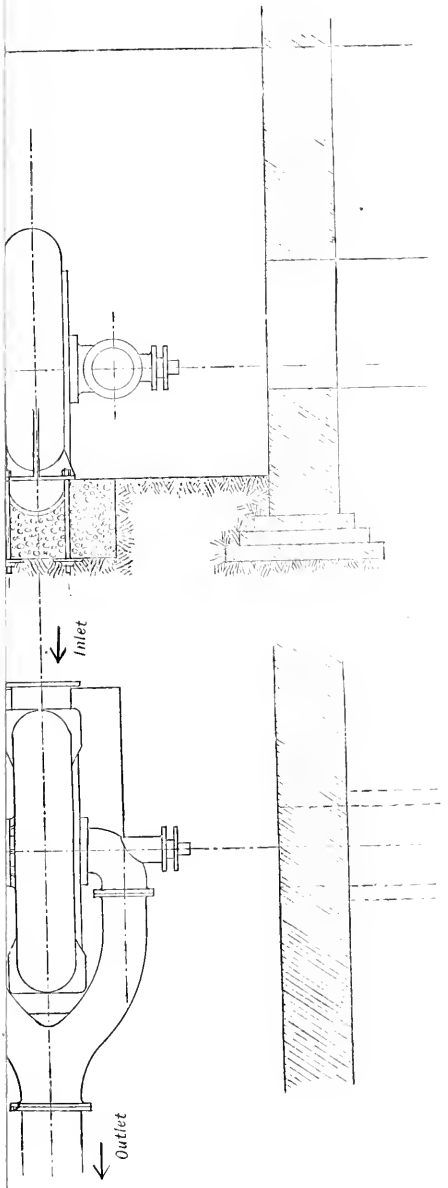


FIG. 7.—THE VORTEX TURBINE, SHOWING INTERIOR.

Fig. 9 is taken from a photograph of a vortex wheel with the cover removed to illustrate the form of the vanes. Some of these do not extend to the central orifice; the object in so making them is that they may not too much fill up the contracted part of the passages, and thus impede the flow of the water.

The wheel is constructed either of steel or of rolled brass (the latter for small sizes), and as the vanes can thus be made very much thinner than of cast metal, their number can be increased, and perfect accuracy in the curvature secured. Hence, the water enters the wheel with less

EVATION



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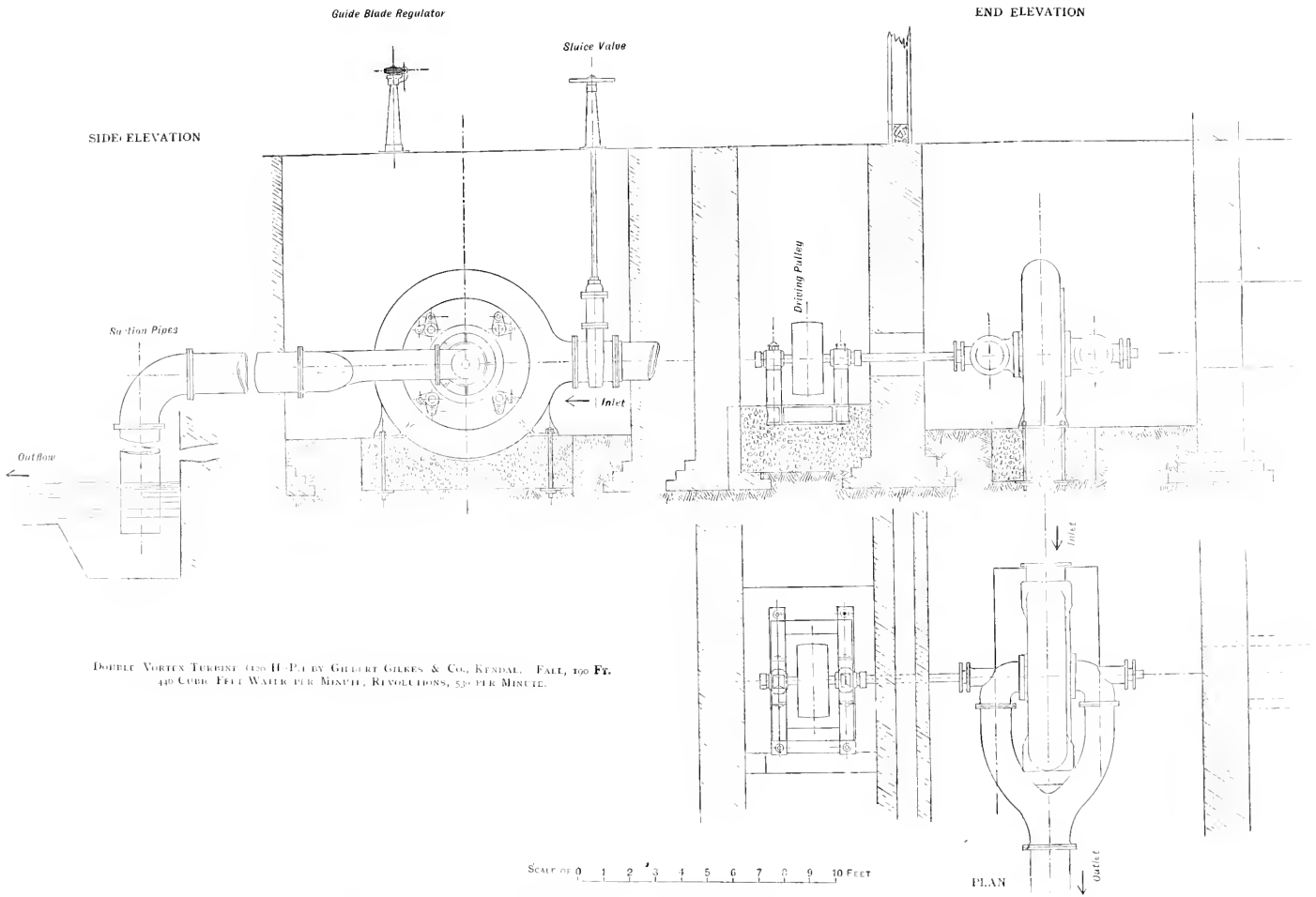


Double Vortex Turbine (120 H.P.) by Gilbert Gilkes & Co, Kendal. Fall, 100 Ft. 440 Cubic Feet Water per Minute, Revolutions, 530 per Minute.

Fig. 8.—Double Vortex Turbine, as installed at the Cwmystwith Mines.

(*To face p.* 8.

interruption, and passes through, more exactly in the direction intended than is the case where the vanes are of greater thickness and fewer in number.

The vanes are fixed on each side of a steel or brass plate, having a boss in the centre to secure it upon the shaft, and two outer discs or covers in which are left circular openings through which the water passes after it has done its work; thus one half of the water is discharged on each side of the wheel.

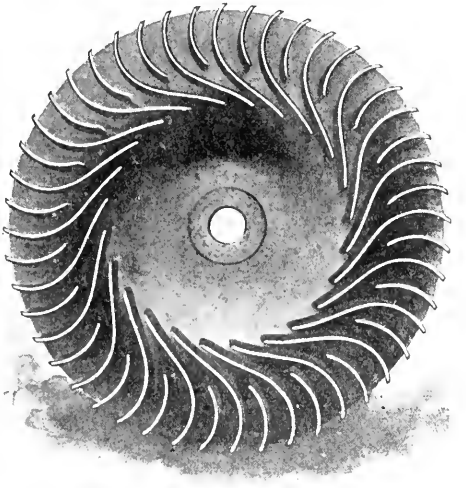


Fig. 9.—The Vortex Wheel Section.

A separate movable cover is placed over the wheel, so that access to it can be had without disturbing the exterior casing. A cover is also placed over the guide-blade chamber in the larger wheels, by means of which access can be obtained to every part without moving the foundations or heavier portions of the case.

The complete wheel is shown in fig. 10, in which the central plate carrying the boss, by means of which the wheel is keyed on to the main shaft, is seen.

For low falls the turbine is arranged to be fixed horizontally, in which case the wheel, instead of being double, as shown in fig. 10, is single, and discharges from the lower side only.

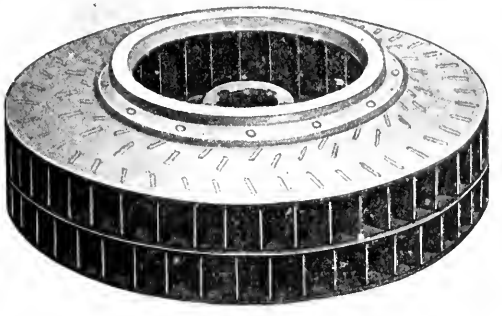


Fig. 10.—The Vortex Wheel Complete.

For all purposes where an even and regular speed is absolutely necessary, as for concentration mills and electric power machinery, a governing arrangement is a necessity. The general arrangement of this

is shown in fig. 10A, on the right-hand side of which is placed an automatic hydraulic governor.

The governor balls when either rising or falling shut off or admit water into the cylinder; and a piston in the cylinder, which is attached to the lever working the guide-blades, rises or falls as the pressure is introduced below or above it, thus opening or closing the guide-blade orifices, and regulating the quantity of water discharged on to the wheel.

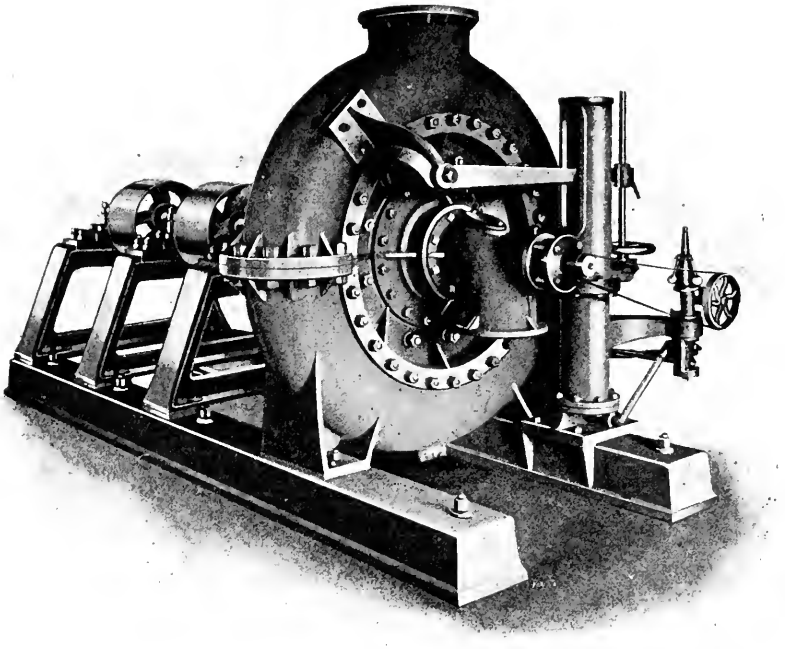


FIG. 10A.—THE VORTEX TURBINE COMPLETE WITH GOVERNOR.

The turbine, governor, and standards for the bearings are all fixed on to two strong beams, and are thus made quite rigid.

The governing of turbines (and the remark applies also to Pelton wheels) is in many cases more difficult than the governing of steam engines, the two chief difficulties to be overcome being the weight of the moving parts and the fact that if the guides or sluice—or, in the case of a Pelton, the spear-rod—are worked too quickly, a very considerable hydraulic shock takes place which may do damage to the pipe line. In the Murray hydraulic governor (fig. 11) the water is, by the action of a high-speed governor, turned to one end or the other of an hydraulic cylinder which works the guide-blades. Such a governor will be seen in the accompanying

illustrations, 1 and 2 being sections at right angles to one another of a four-way valve forming a part of the apparatus, and 3 an elevation showing the complete arrangement. In 1 and 2 the outer casing (A) is provided with a supply port (B), an escape port (C), and other ports (D and E) leading respectively to the top and bottom of a regulating cylinder which controls the supply to the motor. Within the casing (A) is a sleeve (F) provided with ports communicating with an annular passage (G) in the piston (H), which works within the said sleeve. The breadth of this passage (G) is a little less than the distance between the inside edges of the ports, so that when the piston is in a central position the ports (D and E) are closed to the supply, but opened slightly to the exhaust.

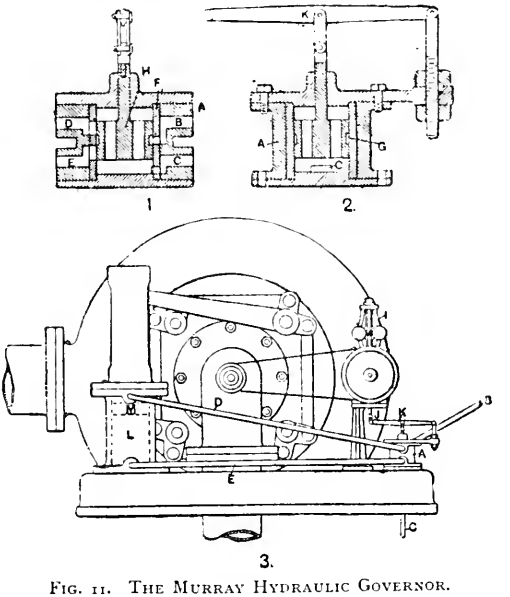


Fig. 11. The Murray Hydraulic Governor.

The action of the apparatus will be seen from fig. 11, in which (I) is a centrifugal governor driven from the motor and connected by the rod (J) with a lever (K), to which the piston (H) is connected by a link. When the speed of the motor increases, the piston is raised, through the governor and lever, and the water passes, by the pipe (D), to the upper part of the regulating cylinder (L), and acts on a piston (M) therein to reduce the supply. Should the speed decrease, the water passes by the pipe (E) to the lower part of the cylinder (L), and raises the piston and permits more water to enter the motor, so as to maintain its normal speed. When a turbine or a Pelton wheel is working under a high fall, a small pipe from the supply will be sufficient for working the governor; but where the fall is low it is worth while to put in a pressure pump to work the governing cylinders.

I have used a regulator of the above type, as shown in fig. 316 (p. 489), to govern a 420 horse-power turbine running at a speed of 450 revolutions per minute under a head of 80 ft., used for driving a generating dynamo where regularity of speed was essential; and another to govern the speed of a 168 horse-power Pelton wheel (Plate II.), driving a concentrating mill and air compressors. In both cases the results were highly satisfactory.

The illustrations in Plate I. (p. 8) are from the working drawings of a double vortex turbine which I erected at a lead and blende concentration mill in Wales in 1899, supplied by Messrs. Gilbert Gilkes & Co., of Kendal, of which the specification is given below. This wheel was not supplied with a governor, but the guide-blades were connected to a hand-wheel, fixed in the interior of the mill, by means of which, once the water was turned on at the main sluice, the wheel could be started, stopped, or its speed controlled. The steel pipes were buried for the whole of their length, and started from a wooden tank in which was a grating to prevent the entrance of leaves or rubbish. The sand and gravel in the water were caught previously in a settling tank, at the bottom of which was a sluice continually open, which carried away any heavy matter deposited.

SPECIFICATION.

Double Vortex Turbine of 120 horse-power adapted for a fall of 190 ft. and designed to use, at the standard opening of the guide-blades, 446 cubic ft. of water per minute. The wheel arranged to make about 530 revolutions per minute. The case of cast iron, the guide-blades of wrought iron, and the revolving wheel of steel. The guide-blades to be movable, for adapting the entrance orifices to any quantity of water below the full supply, and to be fitted with gearing for adjusting them. Arranged to use part of the fall by suction, including the bends with stuffing-boxes, etc.

Shafting and Gearing.—Extension of sluice spindle; extension guide (B) gear; extension of shaft (turbine); two self-oiling pedestals; beams and brackets for ditto; adjusting collars and pulley, 33 in. diameter × 14 in.; second motion shaft and collars; two pedestals (self-oiling); two sole plates and fixing bolts; one pulley, 75 in. × 14 in., and one 48 in. × 21 in.; strainers of cast iron, 48 square ft. in area; one sluice to be placed near the turbine; supply pipes of 16 in. diameter; one Bellmouth, seven bends, 865 ft. of steel piping with Kimberley joints and jointing material; suction pipes of 12 in. diameter, and one 16-in. Y pipe, four 12-ft. lengths, 16-in. flanged, one 16¼-in. bend, and four 9 ft. lengths (bolts and joint-rings included). Unless otherwise specified, all shafting is turned and polished; couplings are turned, bored, and fitted with bolts and nuts; pedestals are bored, turned, and fitted complete, with gun-metal steps.

The tail-race for carrying away the waste water should be of ample dimensions, and care should be taken that the end of the suction pipe should be covered by at least 2 ft. of water, as shown in the plate, by being immersed in a sort of brickwork well formed at the commencement of the tail-race. A safety-valve should be fixed at the lower end of the pressure pipes in order to prevent their being damaged by the sudden cutting off of the water causing hydraulic blows, which may burst the

pipe line. A small air-pipe must be carried from the top of the supply pipe to a point at a higher level than the surface of the head-water. This will secure the pipes running empty when the water is turned off at the top, and will prevent the strainer from being pulled down by suction, should it be so covered with leaves as to stop the inflowing water.

The speed of the water running in the head and tail races should not exceed from 2 to $2\frac{1}{2}$ ft. per record, in order to avoid loss of head. The dimensions of the races must be arranged to take the proper quantity of water at the above speed.

The Pelton Waterwheel.—This wheel is what may be termed a

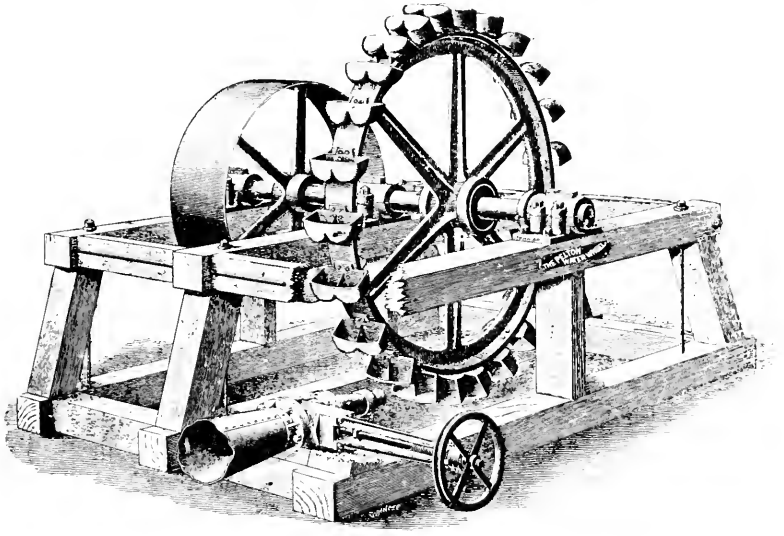


FIG. 12.—THE PELTON WATERWHEEL.

tangential reaction wheel, the power of which is derived primarily from the pressure afforded by a head of water, supplied by a line of pipe discharged upon it through a small nozzle, the size of which is proportioned to the amount of water available and the head and power required. Its general form will be seen by reference to fig. 12, which shows the wheel and its buckets, the nozzle and regulating valve or gate, and the pulley, from which the power is conveyed to other machinery. The wheel itself is in practice hooded in with boards or sheet iron to prevent the splash. The manner of utilising the pressure of the water in the pipes is the distinguishing feature, and the secret of the means by which as much as 88 per cent. of the theoretical energy of the water can be realised.

As will be seen from the drawing, the buckets on the circumference of the wheel are of a peculiar shape, with a wedge in the centre, which divides the stream in such a way as to develop its full force;

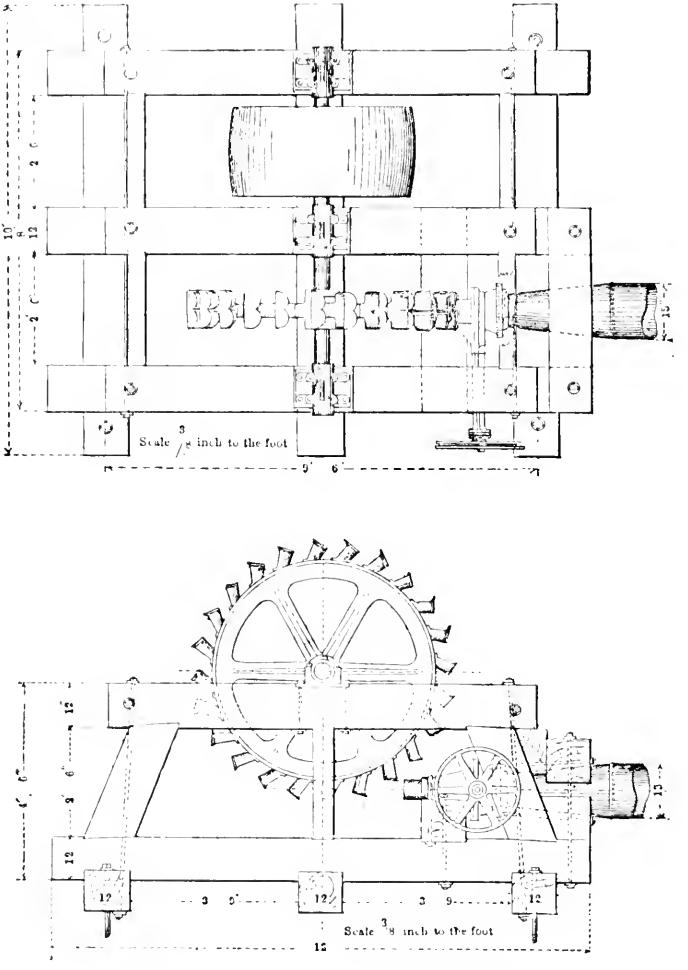


FIG. 13.—6-FT. STANDARD PELTON WATERWHEEL.

while in passing out it sweeps against the curved sides with a reactionary influence, giving it the effect of a prolonged impact. It is also by this means deflected from the course of the wheel, so as to offer no resistance to its motion. That the power of the water is fully exhausted would appear from the fact that it falls from the buckets

practically inert, no water being carried over; nothing but a mist above and a stream below to indicate the force which has been liberated.

The Pelton is essentially a high-pressure wheel, and is not recommended for heads of less than 100 ft.

As regards the extreme pressure consequent upon high heads, there is no practical limit to the head under which it can be operated; as, for instance, at the collar shaft of the Comstock, where a Pelton is at work under a head of 1680 ft., equal to a pressure of 722 lb. per square inch, and realises an average efficiency of 88 per cent. It has been running under these conditions for over three years, and the only repairs needed have been the replacing of a few buckets.

The dimensions of a 6-ft. standard wheel will be found in fig. 13;

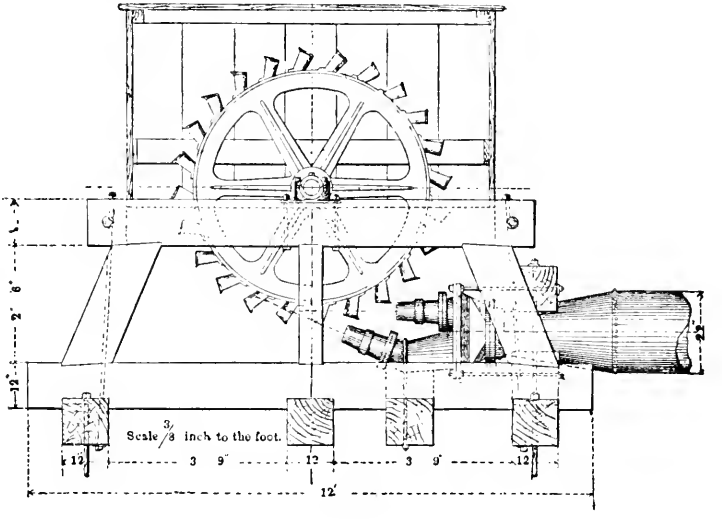


FIG. 14.—6-FT. DOUBLE NOZZLE PELTON WATERWHEEL.

and wheels are made in all sizes downwards, from this to a 4-in. wheel, which can be used for driving a sewing machine or other light work.

The power of a Pelton wheel does not depend upon its diameter, but upon the head and amount of water applied to it. Where a very considerable power is wanted under a comparatively low head, a larger wheel is necessary, in order to admit of buckets of sufficient size to cope with a larger stream of water. Wheels of greater dimensions are also desirable in many cases with reference to reducing the speed, when the smaller will furnish all the power needed.

The velocity of the wheel being determined by the head, the diameter can then be made to conform to the speed required, and the buckets and nozzle delivery proportioned to the amount of water available and power wanted.

When the head of water is low, but the quantity considerable, a wheel with two or more nozzles, as shown in fig. 14, can be employed. Where these are used, one or more nozzles can be stopped off when the additional power they afford is not wanted, or when for any reason the water supply partly fails. Wheels with several nozzles are of great

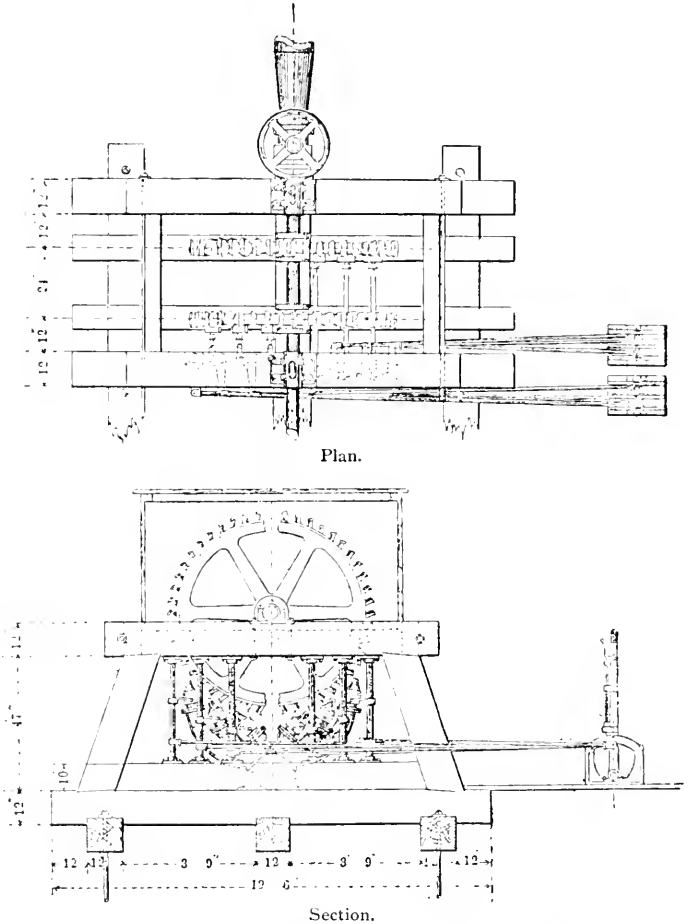


Fig. 15.—The Pelton Waterwheel. Three Nozzle Reversible.

use for hoisting purposes, as in double winding shafts or inclines, where this arrangement admits of using all the streams when starting the load, and shutting off one or more when it rises; affording thus economy of water, and perfect control of the cages or trucks.

A good arrangement of two reversible hoist wheels keyed on one shaft is shown in fig. 15. Three streams are applied to each wheel by

a system of triple nozzles, each furnished with independent stop-valves, which are operated by hand levers placed in a convenient position, and connected by rods and cranks to the valve spindles. The motion can thus be controlled or reversed at pleasure, and adapted to double winding and hoisting purposes.

For single hoisting purposes, where the load can be lowered by a

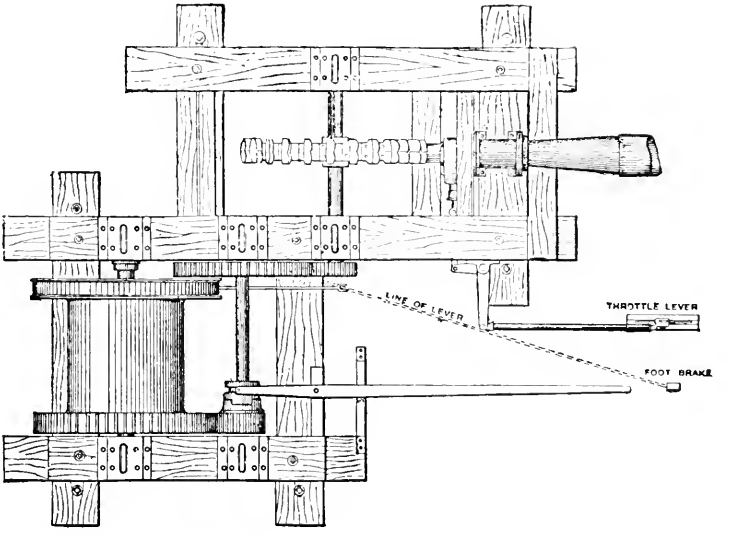


FIG. 16.—PLAN OF PELTON WHEEL AND HOISTING GEAR.

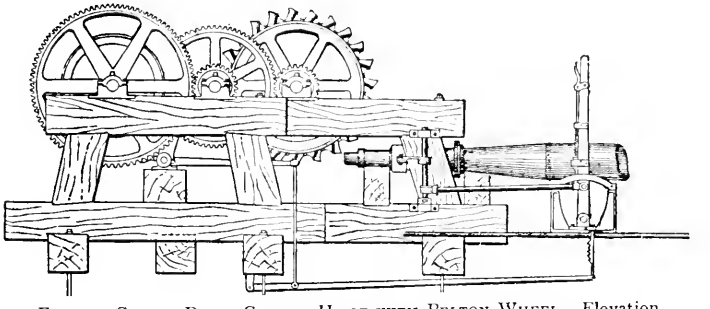


FIG. 17.—SINGLE DRUM GEARED HOIST WITH PELTON WHEEL. Elevation.

brake, the Pelton wheel may be utilised as indicated in figs. 16 and 17, where a single nozzle wheel is connected to a winding drum by means of spur gearing.

The drum can be disconnected by the clutch, and controlled by the brake when lowering; while the quantity of water supplied to the wheel is regulated by the hand lever and water gate. The driver has thus

complete control over the machine, and for winding with a single rope, either from a pit or up an incline, where the weight of the load is sufficient to effect the lowering operation, this arrangement will be found particularly useful.

At the Cwmystwith lead mines in Wales I erected, in 1899, a Pelton wheel 5 ft. in diameter, for the purpose of driving the concentration mill, and also a pair of Schram's 12-in. × 24-in. air compressors. The general arrangement of this plant is shown in Plate II. (fig. 18), which is a reduction of the actual working drawings as supplied by Messrs. Gilbert Gilkes & Co., of Kendal, the makers of the machine, of which the following is the specification:

"One Pelton wheel 60 in. diameter, designed to develop 168 horse-power on 741 ft. fall, using about 160 cubic ft. of water per minute and making 400 revolutions per minute. Fitted Hett's spear regulating nozzle and hydraulic governor.

"Pedestals and sole plates for timber foundation, and wrought iron cover.

"Strainer 30 sq. ft. in area. One 12-in. Bellmouth sluice. One 12-in. slide sluice with bye-pass and pipes. One 4-in. valve and pipes for passing balance of water when turbine is not using full quantity with cast iron connecting pipes.

"Pipes—1815 ft. of 12-in. steel piping, in 25-ft. lengths, with Kimberley joints. Lead and spun yarn for jointing and five steel bends.

"Second motion shaft: one pair of collars; three pedestals with extra long gun-metal steps; sole plates and fixing bolts; one pair of spur wheels with helical teeth about 18 in. and 73 in. diameter, and two leather-lined rope pulleys 10 ft. diameter.

"One pulley 36 in. diameter × 15 in. wide, with friction clutch and lever, etc.

"One relief valve with connecting pipes.

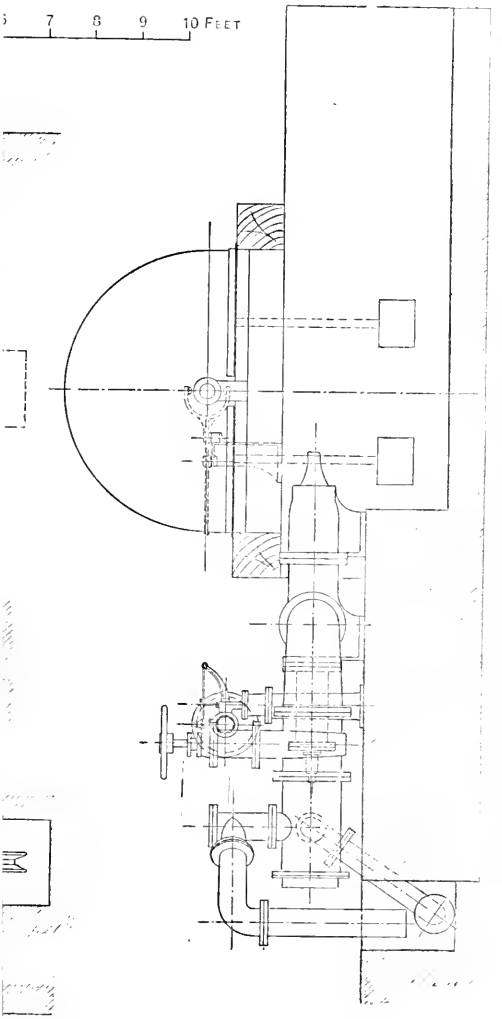
"Anchor plates for pipes."

The concentration plant was driven by means of a cable running from the large grooved pulley, shown in Plate II., and the air compressors by means of a belt from the belt pulley, also shown both here and in Plate IV. (p. 174).

This Pelton was erected and worked without any trouble, the waste water flowing on and supplying the mill with water for the crushers, jiggers, and vanners. The object of the bye-pass, shown around the main sluice, was in order to equalise the pressure of the water on both sides of the sluice, otherwise the great pressure on one side only would prevent its being opened. A draining sluice was fixed in front of the safety-valve and main sluice for the purpose of emptying the pipes when necessary, and the spring safety-valve discharged itself into the same drain.

The regulator worked on the same system as that described on page 11

[PLATE II.



SIDE ELEVATION OF GOVERNOR, NOZZLE AND WHEEL.

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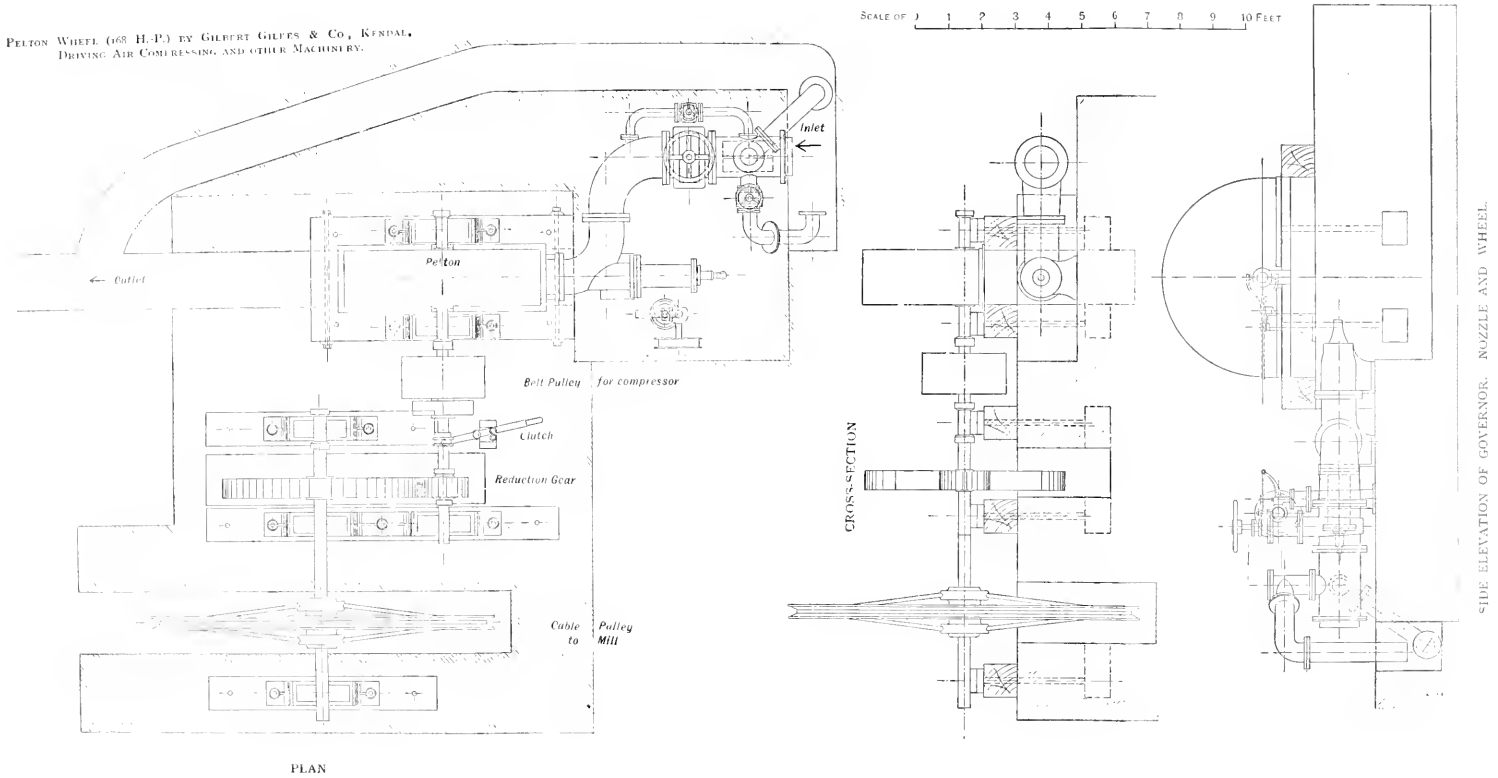

PELTON WHEEL (168 H.P.) BY GILBERT GILKES & CO., KENDAL,
DRIVING AIR COMPRESSING AND OTHER MACHINERY.
Inlet
Outlet
Pelton
Belt Pulley for compressor
Clutch
Reduction Gear
Cable to Pulley Mill
PLAN
SCALE OF 0 1 2 3 4 5 6 7 8 9 10 FEET
CROSS-SECTION
SIDE ELEVATION OF GOVERNOR, NOZZLE AND WHEEL.

Fig. 18.—Pelton Wheel Installation.

(To face p. 18.

(fig. 11), but instead of moving guide-blades, acted upon a spear rod place inside the nozzle of the wheel, and by either pushing it forward closed the nozzle, or by withdrawing it opened it more or less, and so controlled the water-jet and the speed of the wheel.

The uses to which the Pelton wheel may be put are so numerous

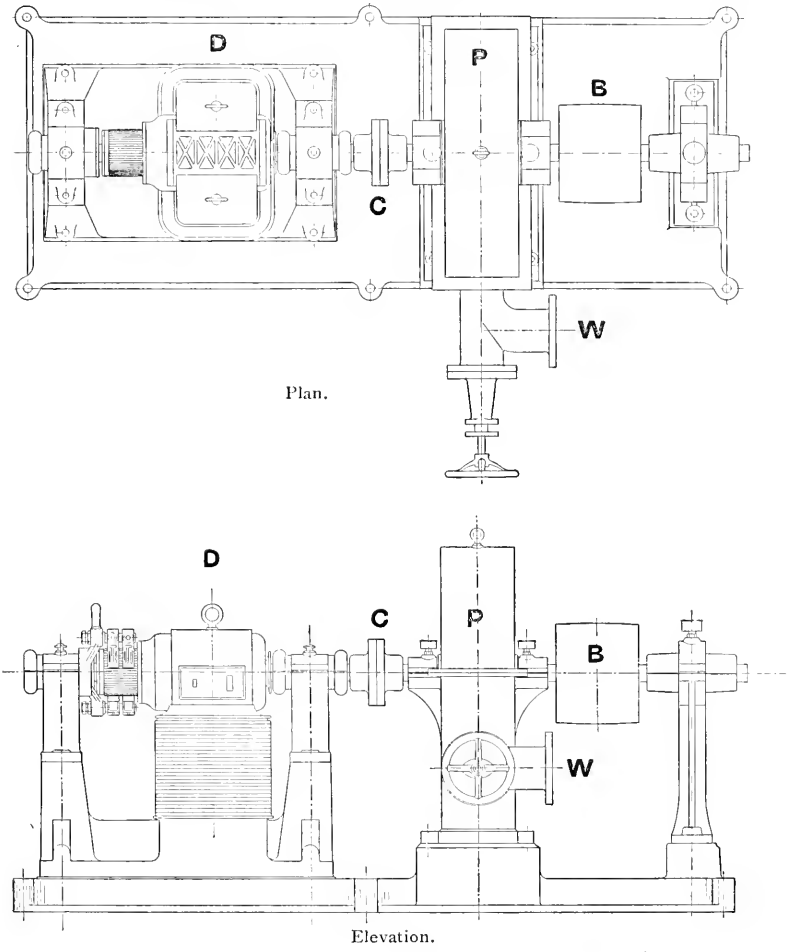


FIG. 19.—PLAN AND ELEVATION OF A DYNAMO AND PELTON WHEEL COUPLED.

that only a few of them can be noticed. By placing the buckets on the flywheel of an air compressor or a pump, the requisite motive force is at once obtained without the use of intermediate gearing. An instance of this is the Riedler pumps of the Niagara Falls Water Works Company. Each of these pumps consists of a duplex double acting Riedler made by

Messrs. Fraser & Chalmers. The plungers are $11\frac{7}{8}$ in. diameter × 30 in. stroke. The capacity is 6,000,000 United States gallons per 24 hours against a pressure of 70 lb. per square inch. The Pelton wheel is 12 ft. diameter, and consists of an extra heavy flywheel, upon which are bolted the requisite number and sizes of waterwheel buckets. The wheel is directly connected on the crank-shaft, and is enclosed in a flanged steel casing and runs at a speed of 75 revolutions per minute.

For driving high-speed dynamos direct, the Pelton is especially suited, and nothing is simpler than to connect one on to the end of a dynamo shaft, both dynamo and Pelton being bolted on to the same bed-plate, and so forming one self-contained machine. In fig. 19 will be seen such an arrangement, which I recently erected at a mine in Wales, for charging accumulators and general lighting purposes. A branch pipe from the pipes supplying the large Pelton, shown in Plate II., was connected up to this smaller wheel, and as the head never varied and the load was constant, no form of governor was necessary. The dynamo (D), fig. 19, and the Pelton wheel (P), are mounted on one solid cast iron bed-plate. The water under a head of 800 ft. arrives at W, and is controlled by the stop valve. The Pelton develops 15 horse-power and this is used for driving a saw bench and lathe when the dynamo is not required. For this purpose a clutch (C) is provided for the purpose of disconnecting the dynamo, and a pulley (B) for connecting the Pelton to a line of shafting by means of a belt.

Directions for Setting the Pelton Wheel.

Pelton wheels are either supplied complete on cast iron bed plates which only require to be bolted down to proper masonry foundations, or, for more temporary work, the wooden framework, shown in figs. 12, 13, is made on the spot, in which case the following directions will be useful:—

Timber Framework.—Make frame as shown in fig. 13, subject to such variations as may be necessary to suit special conditions. See that the framework when in position is level, and the wheel shaft in line with its bearings. Tramp well the earth and rock about the mud-sills until it has a secure foundation, and if the wheel is to develop large power, the mud-sills should be bolted to a stone or wood foundation, set deep in the ground, or on concrete.

Putting on the Buckets.—The wheel should first be put in place on the shaft before putting on the buckets. The buckets after being properly fitted in the shop are numbered and taken off for shipment, and when put on should be fitted to a corresponding number on the rim of the wheel, care being taken in turning up the nuts on bolts. Both head and nut should be firmly seated, but not so tight as to bring an undue strain on the bolts, rendering them liable to give way.

Housing-in the Wheel.—The cover or top housing should extend one inch below the bottom of the boxes on the inside of the timbers, resting on cleats, and left loose so that it can be taken off. For the lower housing, put cleats on the under side of upper

timbers and legs, and on top of sills 2 in. from the outer edge, to allow of boarding double thickness, and making this come flush with the outside of timbers. The ends are boarded on the outside of the legs. A door should be put in opposite the nozzle of the wheel large enough for convenient access to same. The floor under the wheel should be made of 1 in. boards, doubled to prevent leakage. The lower part of the casing for the smaller wheels should have about 12 in. clearance on each side of the buckets, and the larger sizes, say, 22 in. to admit of a free discharge, and the tail-race should have sufficient fall to prevent water backing up on the wheel.

Anchoring Gate and Nozzle.—The gate and standing nozzle should be firmly anchored and braced, especially when working under high heads, so that the force of the water may not move the nozzle or wheel frame from their position. Reliance should not be made in such case altogether upon the wheel frame for securing the nozzle and gate against the pressure of the water, but they should be anchored by rods with turn buckles to masonry or heavy timbers sunk in the ground up stream from the wheel.

Setting the Nozzle.—A template made of Russian iron is sent with every wheel for the purpose of giving the proper setting to the nozzle. The lower edge of the template should rest on the top of the standing nozzle, while the upper curve should conform to the periphery of the buckets. When this adjustment is made, screw the tip into the outer end of the nozzle.

When properly adjusted, the stream will be thrown parallel with the wheel and be divided in its centre by the splitter in the centre of the buckets.

Great care should be exercised in setting the nozzle, as the working results depend largely upon the right application of the stream to the wheel.

Gate, Nozzle, and Tips.—The gate is set behind and in close proximity to the wheel. The nozzle is attached to and forms a part of the gate. The outlet of the nozzle has a thread into which the tips are screwed, which discharge the water on to the wheel. These are short and conical in form, large enough at the butt to make connection with the nozzle, while the discharged end is bored to suit any required delivery, the outlet in the various sizes ranging from $\frac{1}{4}$ in. up to 6 or 8 in. in diameter.

Three tips are sent with each wheel, the largest for the maximum power desired, and the others of reduced capacity. An additional number are furnished where a wide range of power is wanted. Full information as to power should be given for the purpose of making proper adaptation in this regard. A change of tips is but the work of a moment by the use of a wrench or spanner. In putting them on it is advised to use oil to prevent rust, and to facilitate change.

Speed of Wheel.—The speed of the wheels is in all cases determined by the pressure, and they should be geared to run the number of revolutions given in tables under heads named, otherwise they work at a great disadvantage, and will fail to develop their full power. The tables are based upon giving the peripheral velocity of the wheel one-half the spouting velocity of the water. Should the effective head from any cause be reduced, the speed should be made to conform to such change by lagging up the driving pulleys.

It is advisable in all cases to have a gauge connected to the water gate by a small pipe.

This will indicate the running and standing pressure, and show how much head is lost by friction while discharging different quantities of water. An ordinary steam gauge will answer for this.

The following table shows the power of the wheels under different heads and varying diameters, and also the price and weight:—

PRICES, POWER, AND WEIGHT OF PELTON WATERWHEELS.

Standard Sizes.

Head in Feet.	3-ft. Wheel.		4-ft. Wheel.		5-ft. Wheel.		6-ft. Wheel.	
	H.-P.	Price.	H.-P.	Price.	H.-P.	Price.	H.-P.	Price
		£		£		£		£
20	1·50	44	2·64	57	4·18	70	6 00	80
50	5·98	44	10·60	57	16·63	70	23·93	80
80	12·04	46	21·44	59	33·54	74	48·16	85
100	16·84	48	29·93	60	46·85	76	67·36	90
150	31·01	50	55·08	64	86 22	80	124·04	95
200	47·75	53	84·81	70	132·70	85	191·00	100
250	66·74	56	118·54	80	185·47	90	266·96	111
300	87·73	60	155·83	85	243·82	97	350·94	125
350	110·56	64	196·38	92	307·25	110	442·27	140
400	135·08	68	239·94	100	375·40	125	540·35	160
450	161·19	72	286·31	108	447·95	140	644·78	180
500	188·80	78	335·34	120	524 66	155	755·20	200
550	223·76	85	397·43	135	621·82		895·04	
600	248·16	90	440 77	150	689·63		992·65	
700	312·73	100	555·46		869·06		1250 92	
800	382 09		678·66		1061·81		1528·36	
900	455·94		809·82		1267·02		1823·76	
1000	534·01		948·48		1483·97		2136·04	
	Weight, 700 to 1000 lb.		Weight, 1000 to 1700 lb.		Weight, 1400 to 2100 lb.		Weight, 2100 to 3000 lb.	

Measurement of Water.—When the question of the motive power of a mill is being considered, as well as that of the supply of water for the concentration process it becomes necessary to ascertain the quantity of water which is available; and the following are some of the means by which it may be ascertained.

For small quantities of water under, say 120 gallons per minute, the simplest plan is to take a tank or barrel which would fill in from 30 seconds to 60 seconds, and time the operation, and from that calculate the volume in gallons per hour or day, as may be required.

This process cannot be conveniently followed when a small stream has to be measured, and in this case the rate of flow through a known aperture is the basis of the calculation. A board is placed at right angles across the stream in such a manner as to form a pond. A notch is cut in the board an even number of feet long, say two, and of a depth of 6 in. These dimensions vary according to the size of the stream. The edges of the notch should be bevelled towards the up stream, and

the lower edge of it should be at a distance of at least twice the depth of the notch above the level of the bed of the brook so as to give a clear overflow. The board is securely staked down and puddled so that the whole of the water must run over the weir formed by the notch. A few feet up stream within the pond a stake is driven down with its head exactly on a level with the edge of the notch, so that the depth of the water taken by means of a rule from the top of the stake, will be exactly the depth of the water flowing over the edge of the weir. Knowing this depth and the width of the notch we have the bases for the calculation of the quantity which can be readily found from the table on page 24.

This arrangement for measuring the volume of the current of water in a stream, may be constructed either for permanent or temporary observations, and the amount of labour spent upon its erection will depend thereon. In either case great care must be taken to make the dam watertight around the bottom and sides, and to have a clear overfall with the edge of the notch perfectly level. Instead of a stake cut off to the level of the edge of the notch, a stake with a scale of inches attached may be used. In this case the stake is driven as before into the bed of the stream, a yard or so above the dam, and a zero mark made upon it at the exact height of the edge of the notch. A scale of inches and fractions or decimals is started upwards from this zero, and the height of the water above the edge of the notch can thus be read at a glance.

This arrangement of a weir-dam is employed where the whole of the water is to be appropriated to the purposes of the mine and mill. When, however, it is a question of taking only a portion, and paying for that portion, often at a high figure, the plan to be preferred is that described below as miner's inch measurement, reducing the quantities, however, to cubic feet as being the standard upon which all tables of power and efficiency are based.

Miner's inch measurement.—The most scientific way of measuring the quantity of water is doubtless that which gives the answer in cubic feet, and this is indeed the most useful. It is, however, sometimes the custom to calculate and pay for the use of water by the "miner's inch," a somewhat indefinite term, which varies in its application in different countries; as, for instance, the California water companies do not all use the same head above the centre of the aperture from which the water flows, and the inch varies from 1·36 to 1·73 cubic ft. per minute each; but the most common measurement is through an aperture 2 in.

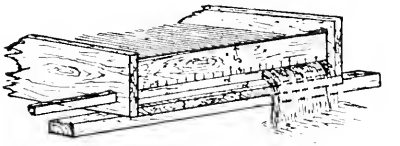


Fig. 20.—Miner's Inch Measuring Board.

Table of Discharge from each Foot Width of Notch or Sill in Cube Feet per Minute (*Molesworth*).

Depth of Water on Sill.	Decimals of an Inch.									
Inches.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.
0	0·0	·162	·46	·846	1·30	1·823	2·34	3·02	3·68	4·4
1	5·15	5·92	6·75	7·62	8·55	9·42	10·4	11·38	12·41	13·49
2	14·57	15·65	16·79	17·97	19·16	20·34	21·58	22·87	24·1	25·44
3	26·78	28·12	29·56	30·9	32·14	33·78	35·28	36·77	38·16	39·55
4	41·2	42·74	44·29	45·78	47·48	49·13	50·73	52·53	54·07	55·62
5	57·58	59·17	60·92	62·83	64·53	66·33	68·29	70·04	71·89	73·9
6	75·70	77·56	79·46	81·42	83·38	85·23	87·24	89·35	91·26	93·26
7	95·38	97·44	99·54	101·6	103·6	105·8	107·9	109·9	112·1	114·3
8	116·5	118·6	120·9	123·1	125·4	127·6	129·8	133·0	134·4	136·7
9	139·0	141·3	143·9	146·0	148·4	150·7	153·2	155·5	157·9	160·4
10	162·8	165·3	167·7	170·2	172·7	175·2	177·7	180·2	182·8	185·3
11	187·9	190·4	193·0	195·6	198·2	200·8	203·4	206·1	208·7	211·4
12	214·1	216·7	219·4	222·1	224·8	227·5	230·3	233·0	235·8	238·5

Depth of Water on Sill.	Decimals of a Foot.									
Feet.	·0	·1	·2	·3	·4	·5	·6	·7	·8	·9
	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.
0	0	6·7	19	34	53	75	99	125	153	183
1	214	246	280	317	357	391	432	472	515	560
2	605	650	697	746	796	845	896	950	1001	1057
3	1112	1168	1228	1284	1335	1401	1465	1527	1585	1633
4	1712	1776	1840	1902	1973	2041	2107	2182	2247	2311
5	2392	2458	2531	2610	2681	2756	2838	2910	2987	3070
6	3145	3222	3302	3883	3464	3541	3625	3712	3792	3875
7	3963	4049	4132	4220	4305	4395	4483	4569	4658	4751
8	4843	4930	5022	5116	5210	5303	5397	5489	5583	5682
9	5778	5872	5970	6067	6165	6264	6364	6463	6563	6664

high and whatever length is required, and through a plank $1\frac{1}{4}$ in. thick. The lower edge of the aperture should be 2 in. above the bottom of the measuring box, and the plank 5 in. high above the aperture, thus making a 6-in. head above the centre of the stream. Each square inch of this opening represents a miner's inch, which is equal to a flow of $1\frac{1}{2}$ cubic ft. per minute.

Time is not to be considered in any calculation based upon a miner's inch measurement.

The apparatus employed to measure the water is shown in fig. 20. It consists simply of a sluice bringing the supply of water, closed at the end by a board in which is a long narrow opening, usually 2 in. or 4 in. deep, which opening can be regulated by means of a sliding shutter. The dimensions are shown on the illustration. The quantity of water is calculated according to the area of the opening, each square inch of which is a "miner's inch," and allows about $1\frac{1}{2}$ cubic ft., or $9\frac{1}{3}$ gallons, to pass through per minute.

The following table will give the quantities in cubic feet which will pass through an aperture as described, per minute :—

Length of Opening in Inches.	Openings 2 inches High.			Openings 4 inches High.		
	Head to Centre, 5 inches.	Head to Centre, 6 inches.	Head to Centre, 7 inches.	Head to Centre, 5 inches.	Head to Centre, 6 inches.	Head to Centre, 7 inches.
	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.
4	1·348	1·473	1·589	1·320	1·450	1·570
6	1·355	1·480	1·596	1·336	1·470	1·595
8	1·359	1·484	1·600	1·344	1·481	1·608
10	1·361	1·485	1·602	1·349	1 487	1·615
12	1·363	1·487	1·604	1·352	1 491	1·620
14	1·364	1·488	1·604	1·354	1·494	1·623
16	1·365	1·489	1·605	1·356	1·496	1·626
18	1·365	1·489	1·606	1·357	1·498	1·628
20	1·365	1·490	1·606	1·359	1·499	1·630
22	1·366	1·490	1·607	1·359	1·500	1·631
24	1·366	1·490	1·607	1·360	1·501	1·632
26	1·366	1·490	1·607	1·361	1·502	1·633
28	1·367	1·491	1·607	1·361	1·503	1·634
30	1·367	1·491	1·608	1·362	1·503	1·635
40	1·367	1·492	1·608	1·363	1·505	1·637
50	1·368	1·493	1·609	1·364	1·507	1·639
60	1·368	1·493	1·609	1·365	1·508	1·640
70	1·368	1·493	1·609	1·365	1·508	1·641
80	1·368	1·493	1·609	1·366	1·509	1·641
90	1·369	1·493	1·610	1·366	1·509	1·641
100	1·369	1·494	1·610	1·366	1·509	1·642

NOTE.—The apertures from which the above measurements were obtained were through material $1\frac{1}{4}$ in. thick, and their lower edge 2 in. above the bottom of the measuring box, thus giving full contraction.

In Running Streams.—An approximate manner in which to obtain the quantity of water in a running stream is by choosing a part of the stream where the section is fairly regular and marking off a convenient distance, say 20 yards, along the bank. Then throw a float (a bottle sunk down to the cork makes a very good float) into the stream, and see how long it takes to travel the distance set out. The experiment should be made two or three times, and the average speed recorded.

The speed thus measured is that of the surface near the centre of the stream. The water moves faster there than elsewhere. Near the bottom and at the sides it flows more slowly. The difference depends upon the nature of the channel. If it is a wooden trough with smooth sides and bottom, take off 15 per cent., if a brick channel, 17 per cent.; if the bottom and sides are earth, 29 per cent. In rough mountain streams 36 per cent. must be taken off the speed.

The average section of the stream must be ascertained, and the area calculated. Now treat the figures as shown in the following example.

Suppose the speed in the middle of the stream to be 100 ft. per minute, and the channel to have earthen bottom and sides, and the area or the stream 18 square ft. First correct the speed, reducing it 29 per cent., and 71 ft. per minute is left. Multiply this by 18-ft. area, and the answer is 1278 cubic ft. per minute

It will be seen that owing to the great variation in the size and character of various channels, this method of measuring water can never be more than approximate.

Power from Water.—The power which may be obtained from a given quantity of water falling through a given height, as in overshot waterwheels, or under a given head, as in turbines or Pelton wheels, varies greatly with the efficiency of the machine which is used to convert it into motive power.

Thus putting the theoretical power due to the weight of the water and the head at 100, we have the following coefficients of efficiency for the various types of water-motor machines usually employed:—

EFFECTIVE HORSE-POWER OF DIFFERENT WATER-MOTORS.

Theoretical power being	1·00
Undershot waterwheels	·35
Poncelet's undershot waterwheels	·60
Breast-wheel	·55
High breast-wheel	·60
Overshot wheel	·68
Turbine	·75
Hydraulic ram raising water	·60
Water-pressure engine	·80
Pelton waterwheel (high pressure)	·85

Tables for Calculating the Horse-power of Water.

Based upon an efficiency of 85 per cent.

Miner's Inch Table.

The following table gives the horse-power of one miner's inch of water under heads from 1 up to 1100 ft. This inch equals $1\frac{1}{2}$ cubic ft. per minute.

Heads in Feet.	Horse-power.	Heads in Feet.	Horse-power.
1	·0024147	320	·772704
20	·0482294	330	·796851
30	·072441	340	·820998
40	·096588	350	·845145
50	·120735	360	·869292
60	·144882	370	·893439
70	·169029	380	·917586
80	·193176	390	·941733
90	·217323	400	·965880
100	·241470	410	·990027
110	·265617	420	1·014174
120	·289764	430	1·038321
130	·313911	440	1·062468
140	·338058	450	1·086615
150	·362205	460	1·110762
160	·386352	470	1·134909
170	·410499	480	1·159056
180	·434646	490	1·183206
190	·458793	500	1·207350
200	·482940	520	1·255644
210	·507087	540	1·303938
220	·531234	560	1·352232
230	·555381	580	1·400526
240	·579528	600	1·448820
250	·603675	650	1·569555
260	·627822	700	1·690290
270	·651969	750	1·811025
280	·676116	800	1·931760
290	·700263	900	2·173230
300	·724410	1000	2·414700
310	·748557	1100	2·656170

Cubic Feet Table.

The following table gives the horse-power of one cubic foot of water per minute under heads from 1 up to 1100 ft.

Heads in Feet.	Horse-power.	Heads in Feet.	Horse-power.
1	·0016098	320	·515136
20	·032196	330	·531234
30	·048294	340	·547332
40	·064392	350	·563430
50	·080490	360	·579528
60	·096588	370	·595626
70	·112686	380	·611724
80	·128784	390	·627822
90	·144892	400	·643920
100	·160980	410	·660018
110	·177078	420	·676116
120	·193176	430	·692214
130	·209274	440	·708312
140	·225372	450	·724410
150	·241470	460	·740508
160	·257568	470	·756606
170	·273666	480	·772704
180	·289764	490	·788802
190	·305862	500	·804900
200	·321960	520	·837096
210	·338058	540	·869292
220	·354156	560	·901488
230	·370254	580	·933684
240	·386352	600	·965880
250	·402450	650	1·046370
260	·418548	700	1·126860
270	·434646	750	1·207350
280	·450744	800	1·287840
290	·466842	900	1·448820
300	·482940	1000	1·609800
310	·499038	1100	1·770780

To reduce heads in feet to pressure in pounds multiply by ·434.

When the exact head is found in above table.

Example.—Have 100 ft. head and 50 in. of water. How many horse-power?

By reference to above table the horse-power of 1 in. under 100 ft. head is ·241470. This amount multiplied by the number of inches (50) will give 12·07 horse-power.

Again—have 200 ft. head and 25 cubic ft. of water. How many horse-power 1 cubic ft. under 200 ft. head = ·321 horse-power. Therefore 25 cubic ft. × ·321 = 8 horse-power. *Answer.*

When exact head is not found in table.

Take the horse-power of 1 in. under 1 ft. head and multiply by the number of inches, and then by number of feet head. The product will be the required horse-power.

Rules for Horse-powers.—In ascertaining the quantity of water required to produce a given power under a given fall, or *vice versâ*, the following rules will be found useful:—

The height of the fall in feet multiplied by the number of cubic feet of water per minute, divided by 706, will give the actual brake horse-power.

The horse-power required multiplied by 706, and divided by the height of the fall in feet, will give the number of cubic feet of water required per minute.

When the available quantity of water and the requisite horse-power are determined, the horse-power multiplied by 706, and divided by the quantity of water in cubic feet per minute, will give the height of fall in feet that will be required to produce the horse-power.

The foregoing figures are based upon 75 per cent. efficiency.

Sizes of Pipes.—Many water-power plants which were otherwise well designed have been rendered inefficient by bringing the water to the turbine in pipes which are too small for the quantity they had to carry. If much water is to pass through a small pipe it must of necessity flow fast. Even for large sized pipes, a higher speed than 6 ft. per second cannot be recommended. High speeds of flow involve a loss of working head. For example: If a pipe 1000 ft. long, with 100 ft. fall is 7 in. diameter, and the quantity of water flowing through it 100 cubic ft. per minute, the speed is 6 ft. per second. The pressure at the bottom of the pipe is 43 lb. per square inch when no water is passing, but when 100 cubic ft. per minute is flowing through the pressure is reduced to $33\frac{1}{2}$ lb. per square inch; this is equal to a loss of 22 ft. head. By using a 9-in. pipe if it was important to make the most of the water power, the loss would be reduced to 7 ft., or only 7 per cent. instead of 22 per cent.

The table on the opposite page will show how important it is to fix upon the right diameter for the pipes, and gives the loss of head per 100-ft. length and the quantity flowing at various speeds.

The thickness of the iron or steel pipes will depend upon the pressure or head, the form of the joints and whether single or double riveted. The practice is to begin at the top end where the pressure is small with these pipes and gradually increase their thickness as head or pressure is gained. It is difficult to fix a rule for this, and the intending purchaser will do well to consult the makers on the point and give them a section of the route of the pipe line so that they may divide it into suitable lengths of different thickness. Owing to the severity of competition the tendency of manufacturers is to use a minimum thickness in order to decrease the weight and price, and this must be guarded against.

Diameter of Pipe in Inches.

Velocity in feet per second.	4		5		6		7		8		9		10		12		14	
	Q	L	Q	L	Q	L	Q	L	Q	L	Q	L	Q	L	Q	L	Q	L
2	10·4	·47	16·3	·36	23·5	·29	32	·245	41·9	·211	53	·182	65·4	·164	94·2	·135	128	·112
2·5	13	·733	20·4	·563	29·4	·453	40	·383	52·1	·329	66·2	·284	81·8	·256	118	·211	160	·175
3	15·7	1·05	24·5	·811	35·3	·652	48·1	·552	62·3	·474	79·5	·409	98·2	·373	141	·3	192	·253
3·5	18·3	1·44	28·6	1·1	41·2	·888	56·1	·751	73	·645	92·7	·557	115	·502	164	·412	224	·344
4	20·9	1·87	32·7	1·44	47·1	1·16	64·1	·982	83·7	·842	106	·727	131	·656	188	·54	256	·449
4·5			36·8	1·82	53	1·47	72·2	1·24	93·3	1·07	119	·92	147	·83	211	·683	288	·568
5					58·9	1·81	80·2	1·53	105	1·32	132	1·14	163	1·02	235	·828	321	·702
6					70·7	2·61	96·2	2·21	125	1·89	159	1·64	196	1·47	283	1·21	385	1·01

Diameter of Pipe in Inches.

Velocity in feet per second.	15		16		18		21		24		27		30		36		42	
	Q	L	Q	L	Q	L	Q	L	Q	L	Q	L	Q	L	Q	L	Q	L
2	147	·105	167	·098	212	·086	289	·075	377	·065	477	·058	589	·052	848	·043	1155	·037
2·5	184	·163	209	·153	265	·136	361	·118	471	·102	596	·091	736	·081	1060	·068	1443	·059
3	221	·235	251	·22	318	·196	433	·169	565	·147	716	·131	883	·117	1272	·098	1732	·084
3·5	257	·32	293	·3	371	·266	505	·231	659	·2	835	·179	1030	·160	1484	·133	2020	·115
4	294	·42	335	·392	424	·348	577	·30	754	·261	954	·232	1178	·210	1696	·174	2309	·150
4·5	331	·53	377	·496	477	·442	649	·382	848	·331	1073	·296	1325	·265	1908	·221	2597	·191
5	368	·654	419	·612	530	·544	722	·472	942	·408	1193	·364	1472	·327	2120	.272	2886	·236
6	442	·942	502	·882	636	·786	866	·677	1131	·59	1431	·526	1767	·471	2544	·393	3464	·338

L = The loss of head in feet for every 100 ft. length of pipe.

Q = The quantity of water in cubic feet per minute.

Useful Memoranda for Hydraulic Calculations.

1 Foot = 12 in. = ·305 metres.
1 Cubic foot of water = 6·24 galls. (say 6¼ galls.) = 28·3 litres = ·0283 cubic metres.
1 Cubic foot of water weighs 62·5 lb.
1 Metre = 39·37 in. = 3·28 ft.
1 Cubic metre of water = 1000 litres = 1000 kilos = 35·32 cubic ft. = 220 galls.
1 Cubic metre of water weighs about 1½ per cent. less than 1 ton.
1 Litre of water = ·001 cubic metres = ·035 cubic ft. = ·22 galls.
1 Litre of water weighs 1 kilogram = 2·204 lbs.
Litres per second × 2·12 = cubic ft. per minute.
Cubic feet per minute ÷ 2·12 = litres per second.
1 Gallon of water = ·16 cubic ft. = 4·543 litres.
1 Gallon of water weighs 10 lb.
Pressure in lbs per square inch = head of water in feet × ·433.
Pressure in lbs per square inch × 2·31 = the corresponding head of water due to such pressure in feet.
When water is flowing through a pipe at 3 ft. per second, the quantity delivered per minute = approximately the diameter of pipe in inches squared.
1 Horse-power = 33,000 ft.-lb. per minute = 550 ft.-lb. per second.
1 French horse-power = 75 kilogrammetres (the weight of 75 litres of water falling 1 metre) per second = 542·5 ft.-lb. per second.
Where Q = cubic feet per minute, and F = fall in feet:—

$$\text{at 80 per cent. efficiency, H.-P.} = \frac{Q \times F}{660}$$

$$\text{at 75 per cent. efficiency, H.-P.} = \frac{Q \times F}{706}$$

$$\text{at 70 per cent. efficiency, H.-P.} = \frac{Q \times F}{754}$$

1 French horse-power at 75 per cent. efficiency, $= \frac{\text{litres per second} \times \text{fall in metres.}}{100}$

CHAPTER II.

WIND ENGINES AND VENTILATING MACHINERY.

Wind as a Motive Power—Modern Wind Engine—Velocity of Wind and Pressure per Square Foot—Horse-power of Windmills, and Cost—The Ventilation of Mines—Box Ventilator—Fan—Root Blower—Guibal Fans—Other Machines—Comparative Table of Ventilating Machines—The Measurement of Ventilation——The Anemometer.

Wind as a Motive Power.—The success with which windmills have been used for pumping and drainage purposes in Holland, and at home in the county of Norfolk, leads one to believe that they could be employed for the same purpose in mining. As a matter of fact, they are but very little used in connection with mines, and this perhaps is due to their unreliability, and to the fact that most mines are situated in mountainous districts, where, owing to the excessive force of the sudden gusts of wind, wind mills would be liable to serious accident, if not to total destruction.

TABLE SHOWING THE VELOCITY OF THE WIND AND PRESSURE PER SQUARE FOOT.

Miles per Hour.	Feet per Minute.	Feet per Second.	Force in lb. per Square Foot.	Description.
1	88	1·47	·005	Hardly perceptible.
2	176	2·93	·020	Just perceptible.
3	264	4·4	·044	
4	352	5·87	·079	Gentle breeze.
5	440	7·33	0·123	
10	880	14·67	0·492	Pleasant breeze.
15	1320	22·0	1·107	
20	1760	29·3	1·968	British gale.
25	2200	36·6	3·027	
30	2640	44·0	4·428	High wind.
35	3080	51·3	6·027	
40	3520	58·6	7·872	Very high wind.
45	3960	66·0	9·963	
50	4400	73·3	12·300	Storm.
60	5280	88·0	17·712	Great storm.
70	6160	102·7	24·108	
80	7040	117·3	31·488	Hurricane.
100	8800	146·6	49·200	

There are some situations, however, and many uses, to which they can be put; amongst others that of driving dynamos for feeding accumulators, so that a short description will not be out of place in a book on mining machinery.

The ordinary form of windmill, as used for grinding corn, is doubtless familiar to most. The modern form of wind engine is shown in fig. 21, the sails of which are made up to 35 ft. in diameter, beyond which the four-armed windmill is to be preferred.

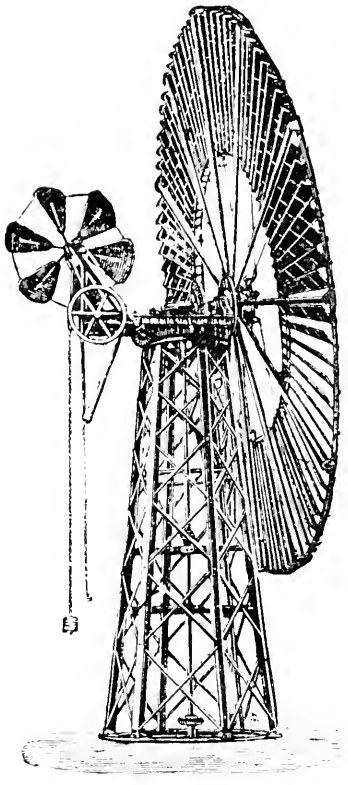


Fig. 21.—Wind Engine.

The sails are mounted on the top of an iron and mild steel latticework, and the shaft on which they work gears into a perpendicular shaft, from the foot of which again any machinery can be driven either by belt or bevel gearing.

The main sails are kept facing the wind by means of the small directing wheel in the rear, which drives a small worm-wheel gearing into fixed teeth on the top of the framework. The main sail is composed of a number of separate boards which can be fully opened when it is required to stop the mill, or partially closed, according to the force of the wind, by means of the chains hanging in the rear, which are connected with the sails through a system of levers worked by a rod passing through the centre of the main shaft. An automatic governing arrangement can be supplied if required, so that the sails will adjust themselves to the variations in the force of the wind, and so maintain an approximately even rate of speed. The pressure of the wind per square foot is a quantity ever varying according to the speed at which the wind is travelling, and this may be ascertained from the table given above. The horse-power of a windmill may be obtained from the following formula (Molesworth):—

HP = Horse-power.
V = Velocity of wind in feet per second.
A = Total area of sails.

$$HP = \frac{AV^3}{1{,}080{,}000} \qquad A = \frac{HP\,1{,}080{,}000}{V^3}$$

The following particulars will show the approximate horse-power, size, and cost of wind engines such as that shown in the illustration :

Approximate Horse-power, Breeze 14 miles per Hour (Pleasant Breeze).	Diameter of Wind Engine.	Price of Wind Engine, without Supports.	Price of Iron and Steel Tower.
$\frac{1}{2}$ horse-power.	13 ft.	£45	£25
$\frac{3}{4}$,,	14 ,,	50	27
1 ,,	16 ,,	60	30
2 ,,	20 ,,	90	40
3 ,,	24 ,,	110	45
4 ,,	28 ,,	180	50
$4\frac{1}{2}$,,	30 ,,	200	55
6 ,,	35 ,,	250	60

The Ventilation of Mines.—The ventilation of metalliferous mines is not surrounded with the same difficulties and dangers as is that of collieries, where, owing to the large quantities of gas given off by the coal, most careful attention has to be paid to the question.

As regards metalliferous mines, especially when they are once opened up, the natural ventilation due to the difference of temperature between the air underground and that at the surface is generally sufficient to supply the wants of the men and to remove the smoke and gases produced when blasts are fired.

The general use of rock drills worked by compressed air has also greatly improved the ventilation in the end of levels and in sinking shafts. Nevertheless, during the process of opening out the mine, especially where rock drills are not employed, means must be resorted to in order to produce a current of air ; while in some mines, especially those in a limestone formation, where large volumes of carbonic acid gas are frequently given off, permanent ventilating machinery must be provided.

A very simple appliance is used in Cornwall for ventilating the end of a level driven from a shaft in which pump rods are working. It consists of two tubs or boxes fitting one inside the other, the outer one being half filled with water and having a pipe running up from the centre of the bottom to about the level of the edge of the tub. On the top of this pipe an ordinary leather clack valve is fixed, opening outwards. The smaller tub is inverted, open mouth being downwards and in the closed top an opening is made also, provided with a clack valve working outwards. An iron rod connects the centre of this tub with the pump rods in such a manner that during their ascent they lift the inner tub and so cause a vacuum to form inside it, into which the air from the level rushes through the central pipe of the outer tub. At the downstroke the air is forced out through the valve in the top of the inner tub.

The depth of the tubs should be greater than the length of the stroke of the pump, so that the inner or working tub may never be lifted above the level of the water in the outer or fixed tub.

The valves should be light, and if possible counterbalanced, in order that the best effect may be obtained. The Struvé ventilator is founded on this principle, and for colliery work is made in sizes

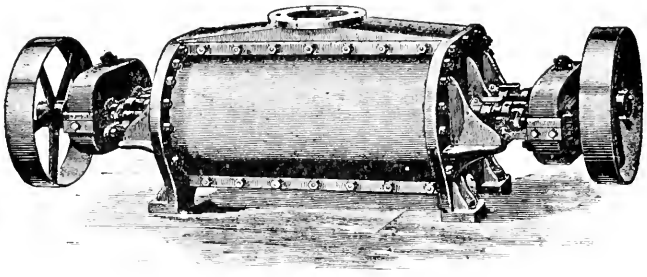


Fig. 22.—Root's Positive Blower.

up to 22 ft. in diameter, capable of giving a theoretical quantity of air of from 20,000 to 100,000 cubic ft. per minute.

The machine most commonly used where small quantities of air only are wanted is the ordinary fan, driven by hand either from a belt wheel or through gearing, and is indeed so very well known, and often constructed on the mine itself, that I will pass on to the more powerful Root blower, which is largely used for ventilation purposes, and is shown in elevation and section in figs. 22 and 23. This blower may be used either for forcing the air into a mine or for drawing it out with equally good effect.

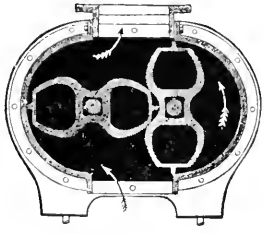


Fig. 23.—Cross Section, Root's Positive Blower.

The outer casting is of cast iron, with the cylindrical parts bored out and the head plates faced. The internal operating parts consist simply of two revolving wings, each cast entirely in one piece, of the section shown in fig. 23.

The wings do not touch in running, but turn as closely as possible together without coming into contact. They are connected together by two cogwheels of equal diameter, and driven by the pulleys shown in the drawing. All the friction is confined to the journals and cogwheels. As long as these are kept in order by perfect lubrication, and not allowed to heat or wear, the blower will continue in order without limit as to time.

The principal sizes in which these ventilating machines are constructed

are given in the following table, as well as the power and speed necessary to work them :

No.	Required Horse-power.*	Displacement per Revolution. Cubic feet.	Minimum Speed.	Maximum Speed.	Size of Pulley. Inches.	Diameter of Discharge. Inches.	Weight. Pounds.	Price.
¼	1	¾	300	350	12 × 2½	5	360	£27
½	2	1½	250	300	14 × 2¾	6	667	39
1	3½	3	225	375	16 × 3½	8	1,400	52
2	5½	5	200	325	20 × 4½	10	1,836	68
3	8	8	175	300	24 × 5½	12	2,740	93
4	11½	13	150	275	30 × 6½	14	4,011	121
5	17¾	23	125	250	36 × 7½	16	6,385	185
6	27	42	100	200	42 × 8½	20	10,811	270
7	40	65	75	175	48 × 10½	24	16,000	360

The machine should be fixed on a firm foundation in a dry place, and perfectly level lengthwise. When used for blowing, the air can be conveyed to them through trunks or boxes, and it is of the utmost importance that the pipes conveying the air under pressure from the blower should be perfectly tight. Leaky air pipes are often used, and often result in the loss of one-half or more of the air. Iron piping of large diameter, with air-tight joints, is the best, as wooden air pipes cannot be made sufficiently tight.

The lowness of the first cost and the ease with which these blowers

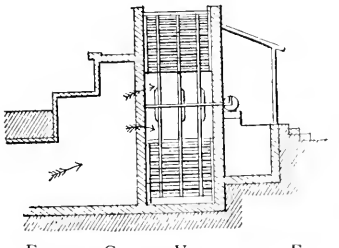


FIG. 24.—GUIBAL VENTILATING FAN (END VIEW).

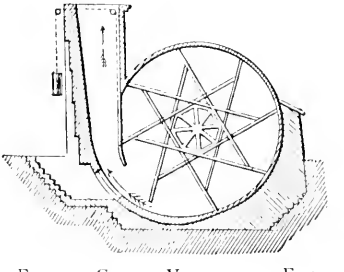


FIG. 25.—GUIBAL VENTILATING FAN (SIDE VIEW).

are erected have led to their being largely used for tunnelling and sinking purposes and the preliminary work of opening up a mine.

For the permanent ventilation of a mine when the natural draught is insufficient, the machine which has met with most favour is the Guibal, which is shown in figs. 24 and 25. The fan varies from 20 to 50 ft. in diameter, and has from 8 to 10 blades inclined backwards and curved at the tips, so interlaced as to form a structure of great strength. The

* Horse-power calculated on ¾-lb. pressure maximum speed.

air can enter at one or both sides. As a rule, one side is placed in communication with the mouth of the shaft and the other is closed by a wall through which the axle of the fan passes, and is driven direct by a single cylinder engine. The general dimensions are given in the table on page 37.

The air is discharged at one particular place, to be determined by experiment and which is closed by an adjustable shutter, so that the exit opening may be regulated into an expanding chimney larger at the top than the bottom, the effect of which is to gradually reduce the velocity before reaching the outside, where the current is out of the influence of the fan.

A Guibal fan, 30 ft. in diameter by 13 ft. wide, driven at a velocity of 100 revolutions per minute, will discharge 100 to 120 cubic yds. of air per second, where a depression of the water-gauge of $1\frac{1}{4}$ to $1\frac{1}{2}$ in. is sufficient.

The percentage of useful effect of the Guibal ventilation at the Hilda Colliery in South Shields is 40, but at the Pemberton Colliery, near Wigan, it is 52·95.

The other ventilating fans before the public are those connected with the names of Waddle, Schiele, and Capell, in addition to which there is the Struvé machine, already mentioned, and the Nixon. This latter is a horizontal double-acting air-pump, with two rectangular pistons of large size supported on wheels which run on rails. The piston works in a closed chamber, the lower half of which is in connection with the pit when the inlet valves are open, and with the atmosphere through the outlet valves in the upper half.

A committee of the North of England Institute of Mining Engineers recently made some investigations as to the efficiency of different kinds of mechanical ventilators as used for collieries;* but the information thus collected will be of great utility to metalliferous miners, and is contained in the tabular statement which follows, compiled from the Report of the Committee by Mr. H. Davey, of Leeds.

The Measurement of Ventilation.—The explosive gases met with in collieries have made it necessary that a daily record should be taken of the quantity of air passing through the workings and of the atmospheric conditions as indicated by the barometer and thermometer. In metalliferous mining, on the contrary, but little attention is unfortunately paid to the state of the ventilation, until it forces itself into notice by the dimness of the lights or the hanging of powder smoke.

The generally accepted rule in collieries where there is no escape

* See "Transactions of North of England Institute of Mining Engineers," vol. xxx., 1880-1.

Efficiencies of Mechanical Ventilators.

No.	Name of Ventilating Machine.	Dimensions of Ventilating Machines.						Dimensions of Engines.				General Remarks.		
		Diameter.	Width, etc.		Theoretical Displacement per Minute.	Diameter of Inlet.	Weight.	No. of Cylinders.	Diameter of Cylinders.	Length of Stroke.	Direct Acting or Geared.	Volume of Air per Minute.	Mean Water-Gauge Pressure.	Percentage of Useful Effect.
		ft. in.		ft. in.	Cubic feet.	ft. in.	Tons.		ft.	ft. in.		Cubic Feet.	Inches.	Per Cent.
1	Guibal	Fan 50 0		12 0	—	15 0	50	1	42	3 6	Direct	108,422	3·30	40·00
2	Guibal	Fan 46 0		14 10	—	13 0	—	1	36	3 6	Direct	246,509	1·85	52·95
3	Guibal	Fan 40 0		12 0	—	14 0	24	1	36	3 0	Direct	170,581	1·46	47·95
4	Waddle	Fan 45 0	Inlet Periphery	6 6 1 5	—	15 0	—	1	32	4 0	Direct	163,312	3·08	52·79
5	Schiele	Fan 12 0		2 1	—	—	—	1	25	2 0	2·57 to 1	157,176	1·91	46·12
6	Schiele	Fan 9 6	Inlet Periphery	3 2 1 8	—	8 0	—	1	20	1 8	$2\frac{1}{2}$ to 1	106,570	2·03	49·27
					rev.									
7	Lemielle	Chamber 22 6 Drum 15 0	Height	32 0	9·9 108,900	—	—	1	55	6 0	Direct	47,307	1·37	23·40
8	Struvé	2 Pistons 18 3	Stroke	7 0	$6\frac{1}{2}$ 47,827	—	—	1	24	4 $4\frac{1}{2}$	4 to 1	43,793	5·11	57·80
9	Nixon	2 Pistons 30 0 long. 2 Pistons 20 0 high.	Stroke	7 0	7·19 120,790	—	—	1	36	6 0	Direct	72,595	2·74	45·91
10	Root	2 Drums 25 0		13 0	16·71 96,918	—	—	2	28	4 0	Direct	89,772	3·29	47·84
11	Cooke	2 Drums 15 0 Casing 22 0		11 6	17·92 80,640	—	—	1	25	3 6	Direct	54,190	1·12	37·33
12	Goffint	2 Pistons 13 2	Stroke	10 $7\frac{3}{4}$	$9\frac{1}{4}$ 53,020	—	—	2	$15\frac{3}{4}$	10 $7\frac{3}{4}$	Direct	36,286	0·71	25·79

of fire-damp is that a minimum of 100 cubic ft. of air per minute is required for each man and boy; and in order that the manager or captain of a metalliferous mine may ascertain for himself, without the use of instruments, the quantity of air passing at any given moment, I annex the two following general methods which were fully described in a paper read by Messrs. Atkinson and Daglish before the Birmingham meeting of the North of England Institute of Mining Engineers in 1861:

(1) "Travelling at the same velocity as the current, and noting the distance passed over in a unit of time."—This was a very primitive mode, but no doubt when used it gave a fair approximation to the truth; for recent experiments have proved that it admitted of great accuracy for velocities up to 400 ft. per minute. It was open to many objections, and would be utterly unsuited to the large mines now existing, since it would be impossible to walk as quickly as the currents travel in the principal splits, and running is not a sufficiently steady pace for the purpose. The process was as follows: Choice was made of a part of the gallery forming the air-way having as uniform sectional dimensions as could be found, and, after measuring off a distance of a hundred or a hundred and fifty yards in length, the operator took a lighted candle and walked in the direction of the current, fully exposing the flame to its influence, but taking care to move at such a rate that the flame would burn in an upright position without being deflected from the vertical, either by the current or by the progress of the person carrying it. The time required to traverse the distance measured off being carefully noted by a seconds watch, the average rate of walking was thereby determined, and three or four trials served to give the assumed velocity of the air-current. This, multiplied by the average sectional area of the part of the air-way selected for experiments, was taken to represent the quantity of air passing in the unit of time.

(2) "Determining from observation the rate at which small particles are carried along by the current, and assuming their velocities to be identical with that of the air-current itself."—Until recently observations of the velocity of the smoke from an exploded charge of gunpowder, in a part of the gallery of nearly uniform sectional area, were the means most generally adopted in the coal mines of this country for ascertaining the velocity of air-currents. They are still considerably used, and so far as regards shaft velocities, they remain the only method. For this purpose an even part of a road should be selected, about 50 to 60 ft. in length, and its cubical contents in feet ascertained. Then let off a flash of gunpowder at the windward end of the channel, and observe the number of seconds the smoke is in passing to the other end. Then say as the time (in seconds) in passing is to the cubic area, so is 60 seconds to the number of cubic feet passing per minute.

Example: Length of channel selected, 60 ft.; height, $5\frac{1}{2}$ ft.; width, 6 ft.; time in passing, 4 seconds. What is the amount of air?

60 ft. × $5\frac{1}{2}$ ft. × 6 ft. = 1980 cubic ft. area; and as 4 : 1980 : : 60 29,700 cubic ft. per minute.

These methods are sufficiently exact for all ordinary purposes, but are liable to various sources of error, though by the use of fixed quantities and distances, and the avoidance of extreme velocities, an approximation to accuracy may be obtained. To secure this, the following precautions are recommended:

(*a*) Always to use one cubic inch of gunpowder as a standard.

(*b*) The velocity of the current never to be less than 100 ft. per minute, nor to exceed 500 ft. per minute.

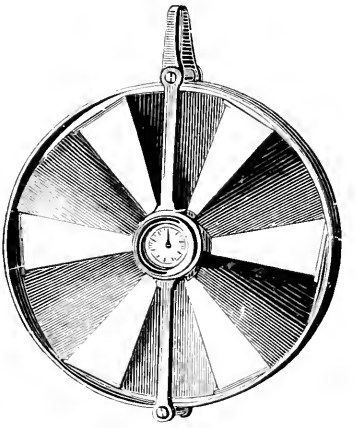


Fig. 26.—The Anemometer.

In order to attain this, a gallery of such area must be selected as will afford this velocity of current.

(*c*) The time not to be less than 12 seconds, nor to exceed 30 seconds.

(*d*) To explode the gunpowder 10 ft. to the windward of the first mark. Therefore, in slow currents of from 100 to 250 ft. per minute velocity, the distance to be taken over which the smoke passes will be 50 ft.; and for the higher velocities, of from 250 to 500 ft. the distance will be increased to 100 ft.

The instrument used in connection with ventilation, for the purpose of ascertaining the quantity of air passing per minute, is called the anemometer, and is represented in fig. 26. It consists essentially of six vanes made of thin sheet brass; these are delicately mounted on a centre moving freely within a brass ring. It is carried by the handle, and indicates the most gentle current, the rate at which the van revolves being noted by the index in the centre of the figure.

To ascertain the number of cubic feet of air passing per minute, multiply the velocity per minute, or, in other words, the recorded number of revolutions by the sectional area of the air-way in feet, and the result will be the quantity in cubic feet.

For the purpose of temporarily increasing the ventilation in a shaft the pump cisterns may be allowed to run over, and so create a water-fall which carries a certain quantity of air down with it, or a steam-jet directed upwards may be placed in the shaft just as a blast-nozzle is placed in the chimney of a boiler. Neither of these methods are economical, and must be regarded only as temporary expedients. Where fuel is abundant, a fire hung in the upcast shaft is an effectual means, but is rarely used in metalliferous mines because of the cost of coal.

CHAPTER III.

STEAM BOILERS, STEAM ENGINES, AND OIL ENGINES.

Boilers—The Egg-end—Cornish—Lancashire—Horse-power of Boilers—The Root Boiler—American Multitubular—Babcocks & Wilcox Boilers—Steel Smoke Stacks—Feed-Water Heaters—Heating Mills—Chimneys, Heights of—Locomotive Multitubular Boilers—Vertical Boilers—Stoking—Steam Engines for Driving Mills—Horse-power of Engines—Mean Effective and Terminal Pressures—Condensing and Non-condensing Engines—The Corliss Engine—The Compound Engine—The Priestman Oil Engine—The Union Oil Engine Hoist—Gas Producers.

Boilers.—Great ingenuity has been displayed by the various boiler-makers, in order to obtain the maximum of evaporative power per pound of fuel, which is the standard of efficiency of a boiler. Generally speaking, boilers may be roughly divided into three classes, of which the Cornish and Lancashire represent the type used for permanent works, the locomotive multitubular boiler for less permanent work and situations where transport is difficult, and the vertical for temporary use.

The plain cylindrical egg-end boiler, from 20 ft. to 30 ft. long × 6 ft. or 8 ft. diameter, fired externally, is now but little used, and in mining would, indeed, be too expensive, owing to its excessive consumption of fuel, its evaporative power being only about 7 lb. or 8 lb. of water per lb. of fuel consumed, as compared with the 10 lb. to 12 lb., which are obtained with Cornish or Lancashire boilers.

The Cornish boiler differs from the egg-end in having flat ends and one internal flue passing from end to end, with the object of increasing the heating surface.

The Lancashire boiler again differs from the Cornish in having two internal flues running from end to end, across which again "Galloway tubes" are fitted as shown in fig. 27. These tubes are used both in the Cornish and Lancashire boilers, and their effect is to increase the heating surface, create a better circulation of water, and also to strengthen the main flue in which they are placed. The Cornish boiler is suitable for small powers, as, if made for great powers, an excessively large furnace flue would be required in order to give sufficient grate surface; and this again, unless made of very thick plates, would be liable to collapse.

The fire grates are fixed inside the main flues, and in practice are

from 5 ft. to 7 ft. long. The products of combustion pass from the fire grate through the internal flue and around the Galloway tubes to the back end of the boiler; then dividing, they return to the front along

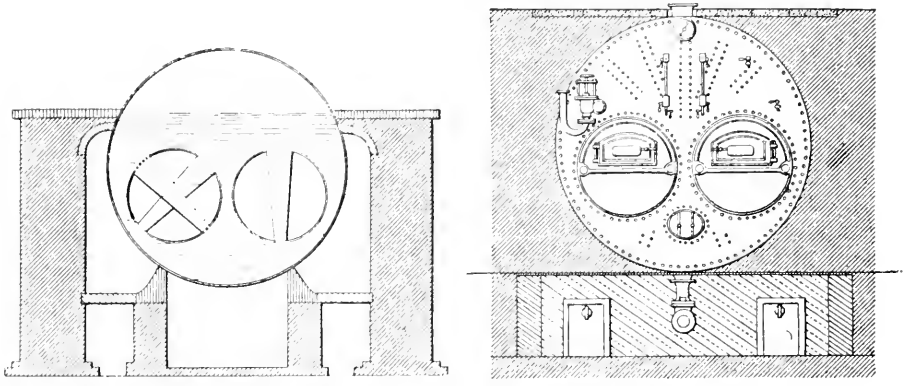


FIG. 27.—CROSS SECTION AND FRONT ELEVATION OF LANCASHIRE BOILER.

two external side flues. Here they pass down to the bottom flue, and re-uniting, pass together underneath the boiler to the chimney.

The boiler is usually constructed of iron or mild steel plates, and the joints are riveted together by either a single or double row of

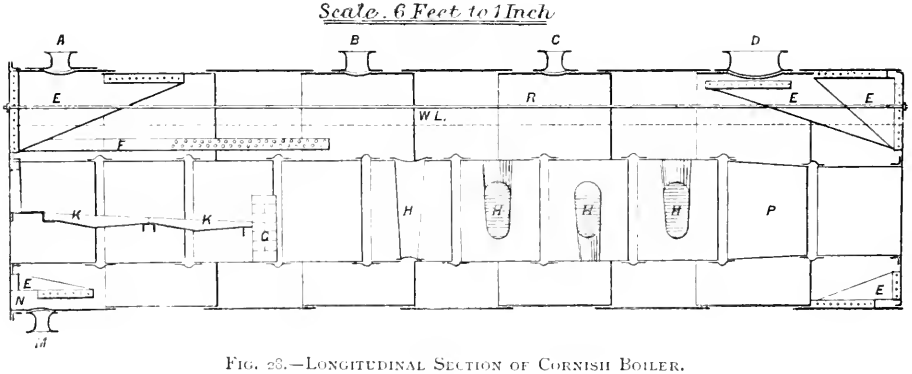


FIG. 28.—LONGITUDINAL SECTION OF CORNISH BOILER.

rivets. Egg-end boilers require no stays on the inside, but the flat ends of Cornish and Lancashire boilers both need gusset stays, shown at E in fig. 28.

The makers furnish plans for the setting of these boilers. The main objects to be aimed at, moreover, are summed up as follows by Mr.

Caleb Pamely, in his "Colliery Manager's Handbook," * in which will be found an excellent treatise on the construction and erection of boilers :

1. The circulation of the gases in contact with the shell, so that the heat of the fuel is utilised to its full extent.

2. The distribution of these gases in such a manner as to equalise the temperature of the shell as far as practicable.

3. The arrangement of flues to give full access to a person to make an inspection of every part of the outside of the boiler.

4. The prevention of loss of heat by radiation from surfaces not exposed to the hot gases.

The general arrangements of a Lancashire boiler will be gathered from figs. 27 and 28, which show the front elevation, side elevation, and longitudinal section of a boiler of this class, and from the following description, which is extracted from the book just mentioned.

The furnace of a Cornish or Lancashire boiler consists of a mouthpiece, having doors provided with a sliding grid, as shown in the front elevation (fig. 27). The furnace bars are made in two lengths, as shown at K K (fig. 28). At the front end these bars rest upon a dead plate, and at the back at a slightly lower level, so that the bars may incline inwards ; they are supported by the firebrick bridge (G) either on a ledge formed on the bridge for that purpose, or on a bearer built into it. In the middle, at the joint of the two lengths, the bars are supported by a cross bearer.

The bridge is usually built entirely of firebrick to within about 20 in. of the crown of the internal flue, but sometimes a cast iron stool is used to carry both the furnace bars and the firebrick. The stool is provided with a sliding door, by means of which the admission of air to the furnace flue is regulated from the furnace mouth. Mechanical feeders may be used for stoking, but they are objectionable on account of their complicated mechanism and the power required.

In fig. 28, A and C are the blocks for the safety-valves, a dead weight valve being placed at A, and a Hopkinson double safety-valve at C.

B is the block for the stop valve, to which is also fitted a perforated or anti-priming pipe inside the boiler, but not shown in the drawing.

D is the manhole block. It is usually oval, but sometimes circular in shape, and is large enough to admit a man to the interior of the boiler to clean and repair it. It is placed in any convenient position on the top of the boiler.

E are the gusset stays, R longitudinal stay.

WL is the water level in the boiler. Modern practice places the low water line at 4 in., and the working level at 9 in. above the furnace crown.

* London : Crosby Lockwood & Son.

H Galloway tubes.

K the furnace bars.

G the firebrick bridge.

P the internal flue, the rings being welded and connected to each other by the bowling hoop-expansion joint.

M is the blow-off cock.

F the feed pipe, extending 8 ft. or 10 ft. into the boiler, and having the inside portion perforated to allow of a gentle distribution of the water all around it.

N a mudhole door for the discharge of sediment from the boiler, shown also in the front elevation (fig. 29).

In fig. 29 will also be seen the feed water pipe and valve, the two glass water-gauges, two gauge cocks, the furnace doors, blow-off cock, and the cleaning-flue doors.

Lancashire boilers work at 110-lb. pressure per square inch, and are at present made to the following dimensions:—

Length, 30 ft.; diameter of shell, 8 ft.; diameter of internal tubes, 3 ft. 3 in.; number of shell rings, 9, made of mild steel, having a tensile strength of 30 tons to the square inch.

Two plates in each ring $\frac{5}{8}$ in. thick; circular seams, lap-jointed double zig-zag riveted, $3\frac{1}{4}$ in. pitch, $1\frac{1}{4}$ in. line to line horizontal seams butt-jointed, with inside and outside strap plates $\frac{1}{2}$ in. thick, pitch $3\frac{1}{16}$ in., $1\frac{7}{8}$ in. line to line in the outer lines, $2\frac{1}{2}$ in. line to line in the centre line. Rivet holes $1\frac{5}{16}$ in., all drilled in position. Diameter of rivets $\frac{7}{8}$ in. of mild steel, machine-riveted. End plates of mild steel $1\frac{1}{16}$ in. thick, the back plate flanged, the front single riveted to shell angle iron 5 in. × 3 in. × $\frac{3}{4}$ in. Internal tubes of mild steel $\frac{7}{16}$ in. thick, 3 ft. 3 in. diameter, the plates having a tensile strength of 22 tons per square inch. Internal tube rings, hand welded, flanged and attached by $3\frac{1}{2}$ in. × $3\frac{1}{4}$ in. × $\frac{5}{8}$ in. angle irons to the end plates.

Five gusset stays at the front and back end plate above the tubes and two below, and one centre gusset. The boiler is subjected to an hydraulic test of 250 lb. to the square inch.

Testing and Power of Boilers.—A boiler should be tested to at least double the pressure it is intended to work at before being sent from the works, an hydraulic pump being used for the purpose, and a close examination for leakages being maintained throughout the test.

According to Molesworth, each nominal horse-power of a boiler requires—

1 cubic foot of water per hour.
1 square yard of heating surface.
1 square foot of fire-grate surface.
1 cubic yard capacity.
28 sq. in. flue area; 18 in. over bridge.

For cylindrical double-flued boilers an approximate rule for ascertaining the nominal horse-power is

$$\frac{\text{Length} \times \text{diameter}}{6} = \text{Horse-power.}$$

According to this rule the horse-power of the Lancashire boiler just described would be $\frac{30 \times 8}{6} = 40$ horse-power.

It is not usual to make these boilers of a larger size than this, as it

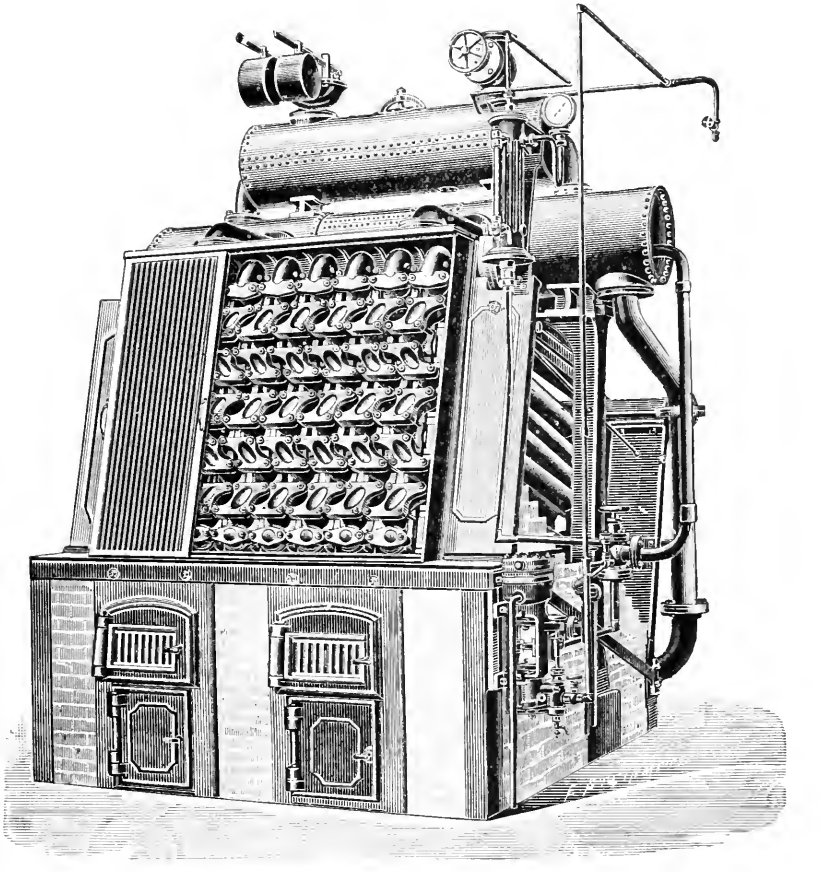


FIG. 29.—THE ROOT BOILER.

is considered more advantageous to increase their number than to increase their dimensions.

The Root Boiler.—The difficulty of transporting large and heavy boilers of the Lancashire, Cornish, and Locomotive types across country,

especially where there are no roads, is obvious, and is not a task to be lightly undertaken. Fortunately the choice of a boiler does not lie amongst these already mentioned, and for general mining work, especially in out-of-the-way places, a boiler or nest of boilers of the well-known Root type, shown in fig. 29, and made by Messrs. Conrad Knap & Co., of London, is very suitable. These boilers, even of the largest size, are made in several parts on the interchangeable principle; and when required

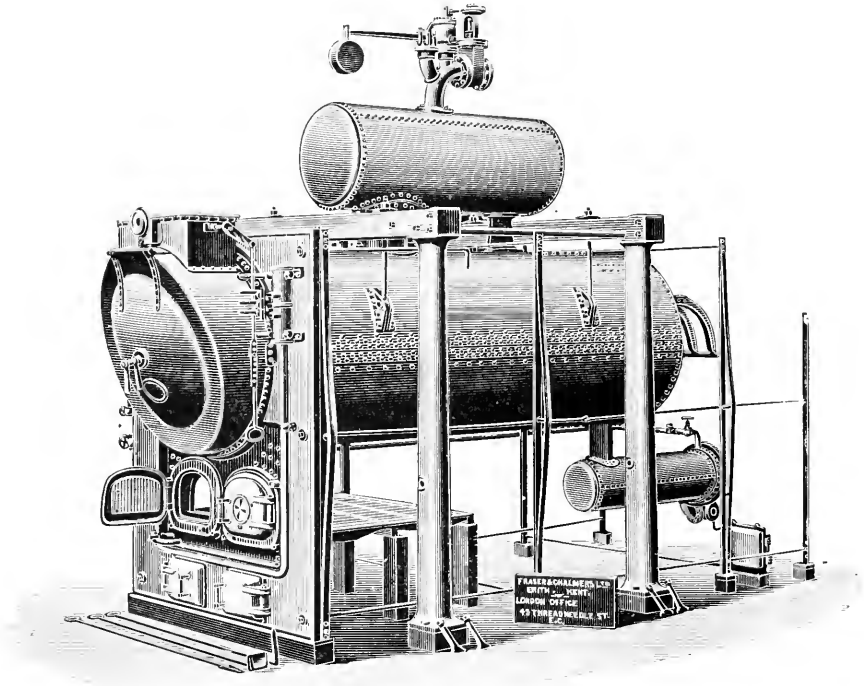


Fig. 30.—Standard Single Multitubular Boiler.

the heaviest pieces can be made to weigh less than 200 lb. each, which can be put together by unskilled labour without riveting or the use of special tools.

As will be seen from the illustration, the steam generating portion of this boiler consists entirely of wrought iron or steel tubes containing water, and enclosed in an outside casing, either of bricks or iron, the latter material being used where the former are difficult to obtain.

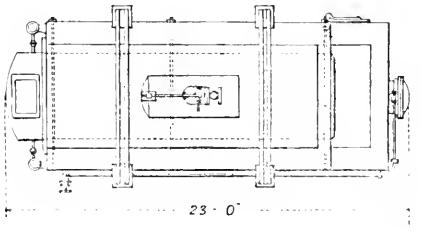
Each tube is fitted with a box or flange at both ends, jointed to each other by hollow connecting pieces. Cross-pipes top and bottom join the vertical tiers of tubes, and a massive iron framework supports the whole, entirely independent of masonry.

The tubes are piled zig-zag to ensure a thorough breaking up of the fire-gases, and the steam space is formed either by tubes, same as the generating portion of the boiler, or by drums of large diameter.

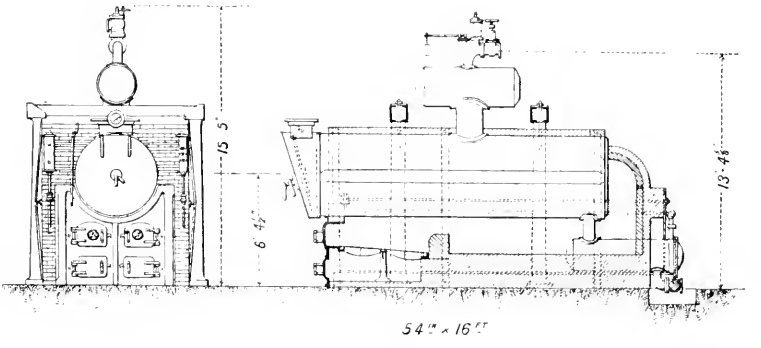
The furnace is arranged underneath or in front of the tubes, and the grate is made of very large size, when required, so as to admit of inferior fuel being used without materially reducing the evaporation of the boiler.

The tubes and connections are made to gauge, so as to be interchangeable throughout, and the framework is planed and fitted accurately so as to make errors in erection impossible with unskilled labour.

The type shown in the illustration is specially suitable for mining



Plan.



Front Half.

FIG. 31.—SETTING OF STANDARD MULTITUBULAR BOILER.

purposes, and wherever transport is difficult. When sub-division of parts is necessary on account of weight, the receivers are made in sections, with faced joints for bolting together.

A type of boiler which finds great favour in the United States is that known as the Standard single multitubular boiler of the column and girder slung pattern, as shown in fig. 30, which has been manufactured by Messrs. Fraser & Chalmers for thirty-five years past. They are made for a working pressure of 140 lb. per square inch, and are tested at 210 lb. The shells in all sizes being in two sheets, butt-jointed and double-strapped.

The principal heating surface in these boilers is contained in the

tubes, which are made of No. 11 gauge; the heat contained in the gases is therefore almost in touch with the water on the outside of these tubes, and the absorption of heat is very rapid and complete, in fact, so thorough that the temperature of the gases entering the uptake rarely exceeds 400° Fahrenheit.

The steam drums are large enough to effectually prevent priming, and the mud drums to collect most of the impurities in any ordinary feed water. Nozzles and connections are all of cast or wrought steel, no cast iron whatever being used.

These boilers may be set in various ways, and the grates made of any size or length to suit the fuel in use. As an illustration of one of the

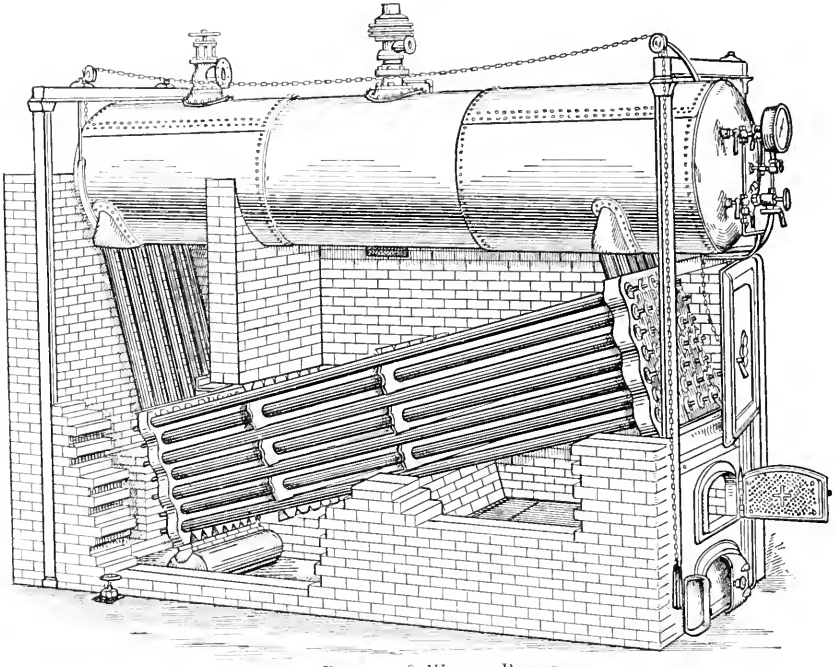


FIG. 32.—BABCOCK & WILCOX BOILER.

usual ways of setting the boiler, the reader is referred to fig. 31, but this is only one of a number of methods which can be varied to suit the special conditions which may prevail.

Babcock & Wilcox Boilers.—The general lines of the construction of these famous boilers is shown in fig. 32, where it will be seen that the furnace flames first play around a nest of water tubes, also underneath a water and steam drum fixed above. The water tubes are connected with each other and at each end with the steam drum, so that the water is in a state of violent circulation.

The boiler is made up essentially of three parts, each connected with the others, and each having a part in the process of steam-raising:

1. *A series of inclined water tubes* over the furnace, in which the water, being divided into small volumes, is quickly raised to a high temperature, and rises through a series of separate connecting boxes, or "headers," at the front end into

2. *A horizontal steam and water drum*, where the steam separates from the water—the water, returning through the vertical tubes at the back end into the inclined water tubes, is again subjected to the action of the fire and once more passes into the steam and water drum; *thus a continuous and rapid circulation in one direction is kept up and a uniform temperature maintained throughout the boiler.*

3. *A mud collector* is attached to the *lowest* point of the inclined water tubes, and into this any matter held in suspension in the water, is, to a large extent, precipitated by reason of its greater specific gravity, as the water falls through the tubes and rear headers.

The tubes are formed of lap-welded wrought iron or steel, expanded at each end into sinuous connecting boxes of steel, each containing one zig-zag row of pipes, and provided with hand-holes for cleaning opposite each water tube—the hand-hole covers being *faced metal to metal* and secured by wrought iron clamps, thus dispensing with all perishable material employed in ordinary joints. A large and continuous water way through all the parts is secured by the end connecting boxes being attached to the horizontal steam and water drum by short tubes, expanded into accurately bored holes. The steam and water drum is made of best flanging quality of iron or selected mild steel, and is double riveted or butt-strapped. The mud-collector is made of a special mixture of cast iron having high tensile strength,—that metal being found to resist corrosion best,—and is provided with ample facilities for cleaning. Where *wrought steel* is demanded it is made of that material.

All the water circulates in one direction, and sweeping swiftly through the boiler scours the tubes, and so prevents (to some extent) incrustation or sediment depositing, except in the mud-collector, whence it is readily blown out.

All unequal strains are avoided by the construction of the boiler; all joints are removed from the immediate action of the fire—the thinnest heating surface, and therefore the most efficacious for the purpose, being made to do the greatest duty; the rapid circulation gives uniform temperature; the parts subject to pressure are small in diameter and of a strength greatly in excess of any pressure they are likely to experience.

The whole structure is suspended on wrought iron girders and columns, and thus the boiler can expand and contract without undue strain; this arrangement allows also access to the brickwork without disturbing the boiler.

The effective heating surfaces are thin, the volumes of water in contact with the heat are small, and receive the flames at right angles to their course. The tubes being zig-zagged, the gases are thoroughly broken up as they rise, and passing into the combustion chamber under the drum they expand and combine before again passing a second and third time through the tubes. Complete combustion, rapid steaming, and consequent economy are thus facilitated. All parts are easy of access, internally and externally, and can be readily kept in order.

The erection of this type of boiler is not a complicated matter and can be carried out by any good bricklayer; the following points should, however be particularly noted:

The Babcock & Wilcox boiler of the W.I.F. type is carried on iron standards, independently of the brickwork, hence the foundation under these standards should be solid.

The brick walls have only their own weight to carry, and require therefore no other foundations than are usually required for walls of the same thickness and height. Where the soil is of a light nature, however, it is desirable to put a block of concrete under the whole surface occupied by the boiler.

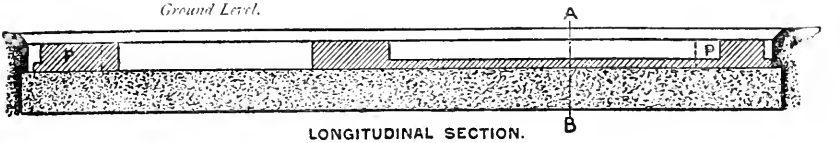
This bed of concrete should be brought up to a higher level at each end, and the upper surface of these raised portions left perfectly level and rendered smooth ready to receive the bases of the iron standards referred to above for carrying the boiler.

The weight of the boiler rests on the raised portions, and the concrete bed should be taken down sufficiently deep at these points to ensure a solid foundation, the depth depending on the nature of the soil.

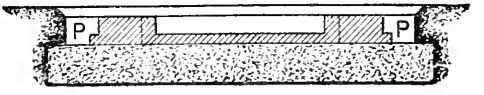
In some cases it is more convenient to make the concrete bed level throughout, with stones bedded on it to carry the bases of the boiler columns. If stones are used, marked P on the illustration, they should be solidly bedded on the concrete, and all at the same level. If the upper surface of the stones should be much above the level of the concrete, they should be bedded on brick piers. In this case the piers should be built of hard brick set in cement.

The joints of the brickwork should be kept as thin as possible. The ordinary bricks should be bedded in ordinary mortar, and the firebricks in fire-clay. It is particularly desirable that the joints between the fire-bricks be as thin as possible. The best thing is merely to dip the bricks in fire-clay mixed with water to the consistency of paint, so that there is no appreciable thickness of joint between the bricks. When the brickwork touches the drum, fire-clay only should be used. Mortar containing lime should not come into contact with any parts of the boiler proper. The cleaning doors should be substantially built in. At the top of the boiler side walls a chase should be left, into which the non-conducting com-

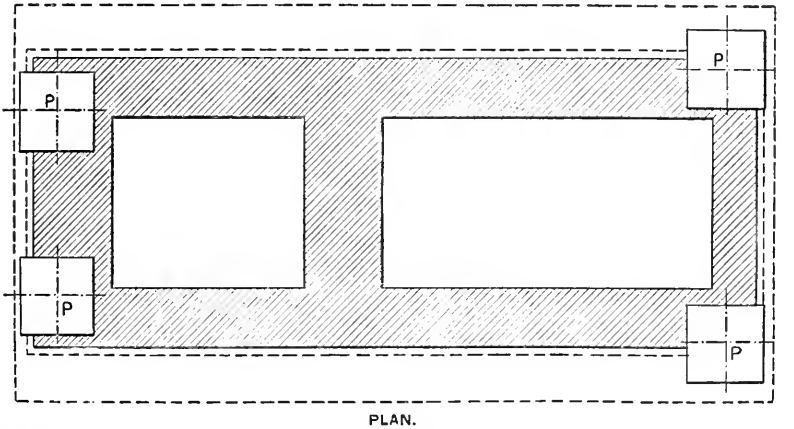
position with which the boiler should be covered is joined. It is an advantage to build the top course of the boiler side walls of hard brick



LONGITUDINAL SECTION.

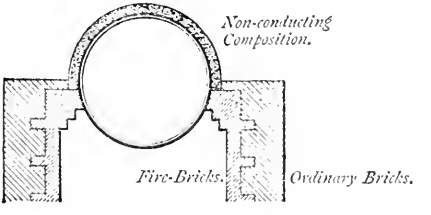


CROSS SECTION A B



PLAN.

THE ABOVE ILLUSTRATIONS SHOW HOW FAR THE FOUNDATIONS AND BRICKWORK FOOTINGS SHOULD BE PREPARED PREVIOUS TO ERECTION OF BOILER.



CROSS SECTION SHOWING FIRE-BRICK LINING TO SIDE WALLS, AND NON-CONDUCTING COMPOSITION COVERING THE STEAM AND WATER DRUM OF BOILER.

FIG. 33.—SETTING FOR A BABCOCK & WILCOX BOILER.

set in cement. For building the arches over the fire-doors, key bricks should be used. The brickwork should be dried for a couple of days

by means of a light fire, and any cracks which may afterwards appear be immediately filled up and re-pointed while the brickwork is hot.

Sectional Steam Boilers.—Messrs. E. S. Hindley & Sons, of Bourton, Dorset, construct sectional steam boilers for facility of transport. The sections, in some cases, only weigh about 160 lb. each, and are so arranged that no special skill is needed in putting the parts together.

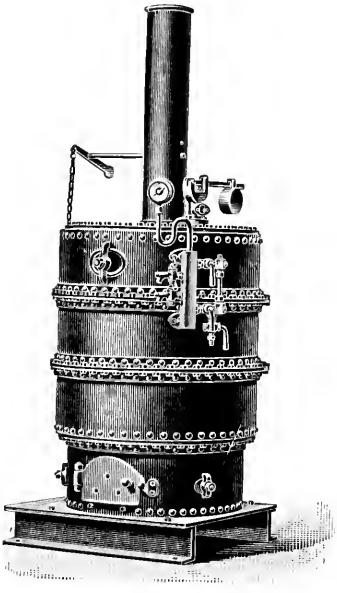


Fig. 33A.—Hindley's Sectional Steam Boiler.

The arrangement of tubes gives a large heating surface in a small compass, while the angle iron joints enable all sediment to be easily removed. The boiler is illustrated in fig. 33A.

Smoke Stacks.—In mining plants—which in many cases are far away from any source of brick supply, it is usual to make the smoke stacks of sheet steel, which are sent out ready for erection with guy ropes, stretchers, damper, and root doors and rivets. When the stacks exceed a height of 60 ft. they are usually built in three courses of different thicknesses of plate. When there is a battery of two or more boilers, a special breeching piece at the foot of the stack and connecting it separately with each of the boilers is required, but the design of this will differ in every case according to the position of the boilers.

The following table will give the proper diameter and height of a chimney for any kind of fuel:

Nom. H.P. of Boiler.	Height of Chimney in Feet.	Inside Diameter at Top.
		ft. in.
10	60	1 6
12	75	1 8
16	90	1 10
20	99	2 0
30	105	2 6
50	120	3 0
70	120	3 6
90	120	4 0
120	135	4 6
160	150	5 0
200	165	5 6
250	180	6 0

The diameter at the base is $\frac{1}{10}$th and $\frac{1}{21}$th the height, and the batter about 0·3 in. to a foot. The thickness of the brickwork from the top downwards is 1 brick for the first 25 ft., $1\frac{1}{2}$ brick for the second 25 ft., and so on increasing by $\frac{1}{2}$ brick for each 25 ft. from the top.

Feed-water Heaters and Heating Mills.—If waste heat from exhaust steam or flue gases is available, a considerable saving is effected by heating the feed-water before it enters the boiler. This saving amounts to as much as 13 per cent. and upwards, if the water is raised from, say 60° to 212° Fahrenheit.

The exposed position of many mills and the climatic influences render it very desirable to have them heated in winter time, in order to prevent stoppage by frost. This may be done by exhausting the steam into a series of pipes running around the mill, or if exhaust steam is not available, then using live steam for that purpose. It is usual to allow one boiler horse-power to supply 300 ft. of 1-in. piping for heating 6000 cubic ft. of space. The coils for heating, or pipes should be fixed so that the condensed water may run by gravity back to the boiler.

Locomotive Multitubular Boilers.—This type of boiler is shown later on in fig. 46 (p. 79), and its construction, being similar to that of a locomotive boiler, is well known.

The great advantages attaching to the use of such boilers for mining purposes are that they require no setting, occupy but small space in comparison with the power developed, have very large heating surfaces, and are the most economical producers of high-pressure steam. They are also easily transported, for which purpose they may either be mounted on a waggon, or fitted with wheels of their own. An iron chimney is used, and so dispenses with a costly erection in brick, which, on the closure of a mine, is often left standing as a valueless monument to departed activity.

These boilers are made in all sizes, from $2\frac{1}{2}$ to 65 horse-power nominal; those under 20 horse-power are made for a working pressure of 80 lb., and those above for one of 100 lb. per square inch; and can be grouped together so as to generate steam for any required horse-power.

Vertical boilers are used for engines of small power, and are generally fitted either with Galloway tubes, or else with a large number of small vertical tubes, through which the hot gases pass into a smoke box above, and at the foot of the chimney. There are many other types which have been designed for special purposes, such as the water-tube boilers, in which the hot gases from the furnace play about a large number of parallel tubes, through which water is passed, and which are connected with a steam receiver above. These are very rapid generators of steam, and are suitable for special purposes. Their portability has caused them to be frequently used for mining purposes.

Boilers are frequently put in the charge of untrustworthy and unskilled attendants, in whose hands they quickly deteriorate, and the length of their life reduced considerably from a maximum of thirty years.

Stoking does not consist solely in shovelling on fuel at irregular intervals, and filling up with water as soon as convenient after it has gone out of sight in the gauge glass. Unless care is used in the firing, much smoke is created. The fuel should be fed frequently, and in small quantities, which should be evenly spread over the surface of the fire-grate so as to leave none of the bars visible. Clinkers should be removed as soon as formed, the steam maintained at an even pressure, and not allowed at one moment to blow off vigorously, while at the next it is below working pressure: a state of things caused by spasmodic stoking, and intense firing at intervals.

The feed water should be heated by means of the exhaust steam, and the level of the water in the gauge carefully watched and maintained at frequent intervals.

The boilers must be blown off, say, once a week, or fortnightly, according to the quality of the water used, and then allowed to cool gradually before being filled up with a fresh supply. If artificial means are used to cool down a boiler, in all probability damage will be done by the rapid contraction of the plates; and again, when raising steam from cold water, rapid firing must not be allowed, as the opposite effect of expansion may create mischief.

In short, it will be more economical in the long run to pay good wages to an intelligent and skilled stoker, rather than entrust a machine like a boiler with immense potentiality for dealing destruction around to the first bumpkin who wants a job.

Steam Engines for Driving Mills.—Steam has been so largely used in mining operations, and for so long a time as a motive power for driving the winding and mill engines, that it is now almost assumed that, because a man is a miner, he is also practically acquainted with the working of engines. It is, however, impossible for any one to carry in his head all the formulæ in connection with steam, and for this reason I will give a few of those in most frequent use before proceeding to describe the type of engine now in use.

The power of an engine is compared with that of a horse, and this latter is assumed to be that equal to raising a weight of 33,000 lb. one foot high in a minute. The term "nominal" horse-power, as applied to engines, is vague and misleading, and varies according to the make of the engine.

The actual or I.H.P.—indicated horse-power—of an engine is from two-and-a-half to three times the nominal, so that the I.H.P. alone should be used as a standard.

For non-condensing engines the actual horse-power may be obtained by the following formula :

Let p = the mean effective pressure of steam in lb. per square inch, less 3 lb. per square inch frictional allowance.
,, A = the area of the cylinder in square inches.
,, L = length of stroke in feet.
,, N = the number of strokes per minute = revolutions × 2.
,, $H.P$ = horse-power.

$$H.P = \frac{p\,L\,A\,N}{33{,}000}$$

The mean effective pressure is the average pressure of the steam throughout the stroke, and may be obtained from the following table, according to the initial pressure in cylinder, and the point at which the steam is cut off.

The area of the cylinder is the diameter in inches, squared (that is, multiplied) by itself, and then by ·7854.

Condensing engines are not used for winding purposes, owing to the rapidity of the motion, and the frequent stopping and starting. For other purposes, such as pumping and driving the mill, or air compressors, they can be used to great advantage, especially where fuel is scarce and expensive.

The effect of a good condenser and air-pump should be to make available 10 lb. more mean effective pressure with the same terminal pressure, or to give the same mean effective pressure with a correspondingly less terminal pressure.

When, for example, the load on the engine requires 20 lb. M. E. P., the condenser does half the work ; at 30 lb. one-third ; at 40 lb. one-fourth, and so on. It is safe to assume that the condenser will save practically from one-fourth to one-third of the fuel, and it can be applied to any engine, cut-off or throttling, where a sufficient supply of water is available.

The amount of feed-water and coal consumed by an engine varies greatly between 20 to 60 lb. of feed-water, and from 2 to 7 lb. of coal, per I.H.P. per hour, according to the make of the engine.

Condensing engines, in addition, require from 20 to 30 gallons of water to condense the steam represented by every gallon of water evaporated, or roughly from 1 to 1½ per gallon per I.H.P.

Separate Condensers.—As a rule, the question of condensing or non-condensing is settled before the engine is ordered ; but if it is desired to convert a non-condensing into a condensing engine, this can readily be done by the use of a separate condenser, either of the jet or the surface type. The question as to which of these, depends upon the supply of water for condensation. If this is clean and such as

MEAN EFFECTIVE AND TERMINAL PRESSURES.

POINTS OF CUT-OFF.

Initial Pressures.			1/8		3/16		5/32		4/16		1/2		Initial Pressures.
	M. E. P.	Ter.	M. E. P.	Ter.	M. E. P.	Ter.	M. E. P.	Ter.	M. E. P.	Ter.	M. E. P.	Ter.	
40	13·46	11·79	17·34	14·49	20·75	17·11	23·70	19·80	26·22	22·44	30·50	27·78	40
45	16·15	12·87	20·39	15·81	24·13	18·67	27·32	21·61	30·08	24·49	34·75	30·33	45
50	18·85	13·94	23·45	17·13	27·50	20·24	30·94	23·42	33·95	26·55	39·00	32·88	50
55	21·54	15·00	26·50	18·45	30·87	21·80	34·56	25·25	37·81	28·60	43·25	35·43	55
60	24·24	16·08	29·56	19·77	34·24	23·37	38·18	27·04	41·68	30·66	47·50	37·98	60
65	26·93	17·15	32·61	21·09	37·61	24·94	41·80	28·85	45·54	32·71	51·75	40·52	65
70	29·63	18·23	35·67	22·41	40·98	26·51	45·42	30·66	49·41	34·77	56·00	43·07	70
75	32·32	19·31	38·72	23·73	44·35	28·07	49·05	32·47	53·27	36·82	60·25	45·61	75
80	35·02	20·39	41·78	25·05	47·72	29·64	52·68	34·28	57·14	38·88	64·50	48·16	80
85	37·71	21·46	44·83	26·37	51·09	31·20	56·31	36·09	61·00	40·93	68·75	50·70	85
90	40·41	22·54	47·89	27·67	54·46	32·77	59·94	37·90	64·87	42·99	73·00	53·25	90
95	43·10	23·62	50·94	29·01	57·83	34·33	63·57	39·71	68·73	45·04	77·25	55·79	95
100	45·80	24·70	54·04	30·33	61·20	35·90	67·20	41·52	72·60	47·10	81·50	58·34	100

The initial and M. E. P. in above table are pressures above atmosphere and for non-condensing engines; the terminal pressures are absolute, *i.e.*, reckoned from perfect vacuum (14·7 lb. below atmospheric pressure).

can be used afterwards for feeding the boiler, then the jet condenser should be employed. If, on the other hand, the water is dirty and unfit for boiler use, the surface condenser is the most suitable. In the jet condenser the exhaust steam comes in contact with a spray of cold water, and, being condensed, creates a partial vacuum. An air-pump is required to remove to the condensed steam and injected water, and this hot water can be used to feed the boiler.

In the surface condenser the exhaust steam does not come into direct contact with the cold condensing water. The condenser resembles a small multitubular vertical boiler, through the tubes of which a current of cold water is constantly circulated. The steam exhausts into the shell of the boiler, and coming into contact with the numerous cold tubes, is condensed, the same effect being obtained as in the jet condenser, except that the water from the condensed steam does not mingle with that

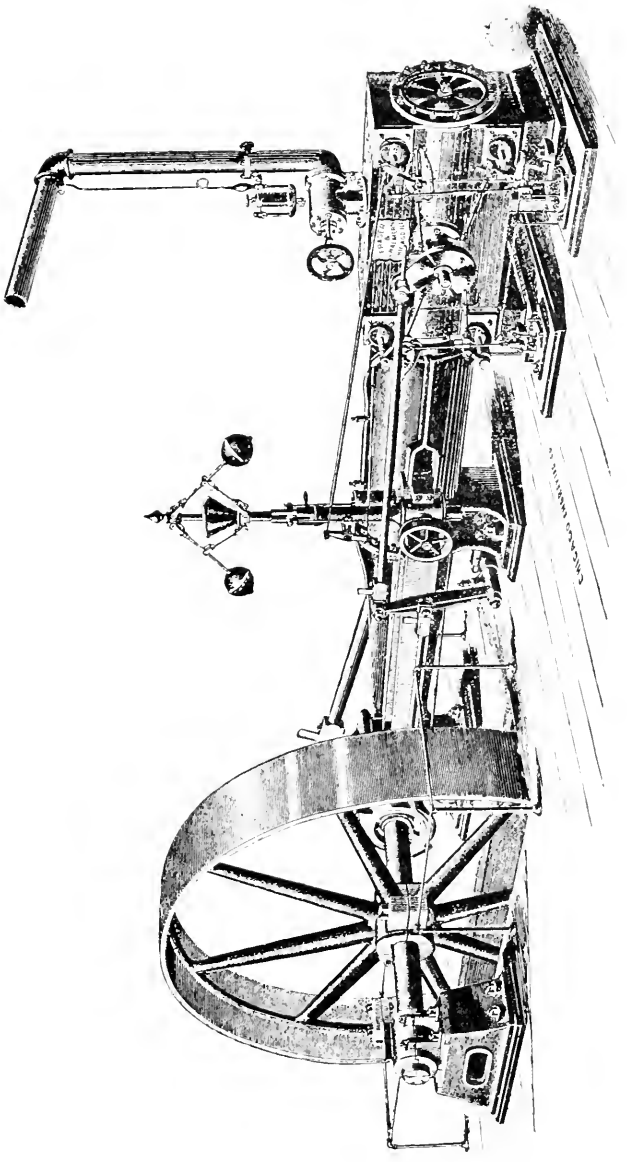


FIG. 31.—IMPROVED CORLISS STEAM ENGINE

employed for condensation. The hot water from the condensed steam is removed by means of an air-pump, and can then be returned to the boiler.

The pumps of independent condensers are driven either by means

of a belt from a pulley on the engine shaft, or from a rocker shaft, which in turn is driven from a connecting rod attached to the crank pin of the engine. In other cases they are made completely independent of the existing engine, and the air-pump is driven by a small steam cylinder direct as shown in figs. 102 and 103 (page 142).

The Corliss Engine.—The competition between the various machinery makers with a view to produce the engine which would work with the greatest economy of fuel, has led to many and great improvements which are, indeed, too numerous to mention. As a type of the class of engine which has attained nearest to perfection, the Corliss may be taken as an example. It is made in three classes: the improved non-condensing (fig. 34), the condensing, and the improved compound condensing; for which latter it is claimed that it consumes 30 per cent. less fuel than any non-condensing engine.

The special feature of the Corliss engine, which distinguishes it from all others, is the valve gear. There are two inlet steam valves one of which is shown in section at 13 (fig. 35), and two exhaust valves, 14 (fig. 35). By means of the peculiar motion transmitted to these valves through the wrist plate (30) driven by the eccentric rod, (49) the steam valves are opened quickly at the beginning of the stroke, thus allowing the steam to enter the cylinder at its full pressure, and are promptly closed at the point of cut-off. The exhaust valves also are opened swiftly and closed slowly, thus allowing free escape to all the steam and preventing back pressure piston.

At the point of cut-off, which is most effective at 2-10ths of the engine-stroke, but which is regulated by the load on the engine through the action of the governor, the steam valve is released, and at the same time is promptly closed by the dash-pot arrangement (65, figs. 35 and 36). Expansion of the steam now commences, and continues until the exhaust valve opens at the end of the stroke, thus ensuring the greatest economy in its use.

The general arrangement of the various parts will be gathered from a study of figs. 34, 35, and 36 (pages 57 and 59).

The Corliss engine is made in all sizes, either vertical or horizontal, according to the space at disposal, and the following particulars of a compound condensing engine of the twin type, shown in figs. 37 and 38, of 332 indicated horse-power, as erected at the works of the Blue Bird Mining Company, Limited, Butte, Montana, for driving a 90-stamp dry crushing mill, will be of interest. The engines, made by Messrs. Fraser & Chalmers, are of the twin type, with the high-pressure cylinder working on one crank and the low-pressure on the other, the crank being set at right angles to each other.

The heavy flywheel necessary for a single engine of the same power

in order to balance the action of the engine, is not required with the double engine, as one crank helps the other over the dead centres.

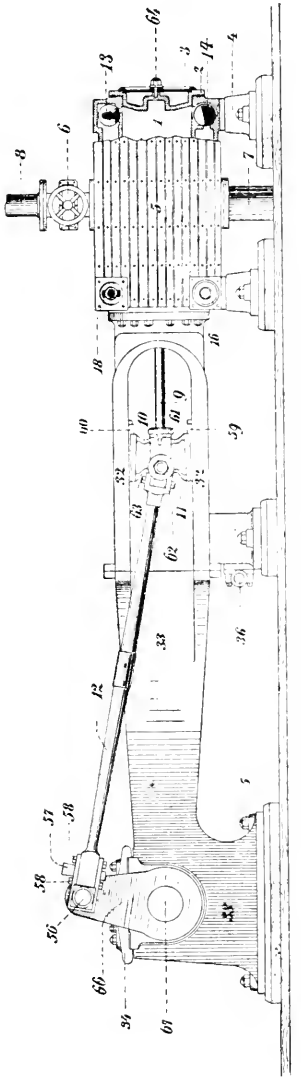


FIG. 35.—THE CORLISS ENGINE. OUTLINE VIEW WITH PARTS NUMBERED.

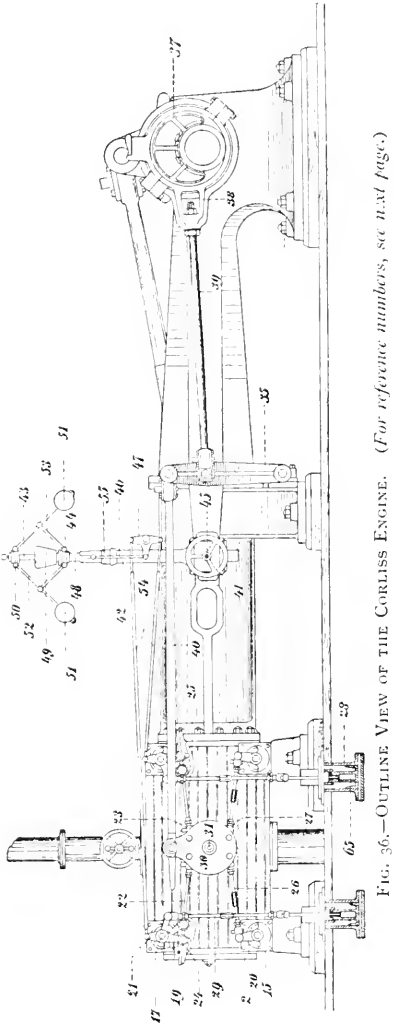


FIG. 36.—OUTLINE VIEW OF THE CORLISS ENGINE. (*For reference numbers, see next page.*)

It is replaced by two belt-wheels, each 18 ft. diameter by 31 in. face, placed one on each side of a central bearing, which thus relieves the main bearings of a considerable weight.

The high-pressure cylinder is 22 in. diameter and the low-pressure

Reference Numbers to Figs. 35 and 36.

Nos.

1. Cylinder.
2. Cylinder head.
3. False cylinder head.
4. Cylinder feet.
5. Walnut lagging for cylinder.
6. Stop valve.
7. Exhaust pipe.
8. Steam pipe.
9. Piston rod.
10. Cross head.
11. Wrist pin.
12. Connecting rod.
13. Steam valve.
14. Exhaust valve.
15. Valve bonnet.
16. Valve covers.
17. Long valve stems.
18. Short valve stems.
19. Steam valve cell cranks.
20. Exhaust valve levers.
21. Brass cut-off cams.
22. Steam valve rods.
23. Butt for steam valve rods.
24. Crab claw.
25. Crab claw spring.
26. Exhaust valve rods.
27. Butts for exhaust valve rods.
28. Compression dash-pot.
29. Dash-pot rod.
30. Wrist plate.
31. Wrist plate cap (brass).
32. Guide piece of engine frame.
33. Crank piece of engine frame.
34. Main bearing cap.
35. Rocker arm.
36. Rocker arm shaft.
37. Eccentric cam.
38. Eccentric strap.
39. Eccentric rod.
40. Second eccentric (or hook) rod
41. Governor pulley.
42. Governor stand.
43. Governor spindle.
44. Governor collar.
45. Governor pulley shaft.
46. Governor connecting rod.
47. Governor bell crank
48. Governor sleeve (brass).
49. Governor centre weight.
50. Governor knob.

Nos.

51. Governor balls.
52. Governor arm.
53. Governor hanger.
54. Governor cut-off rods.
55. Foundation bolts.
56. Crank pin.
57. Key for connecting rod strap.
58. Strap bolts for connecting rod.
59. Lower brass gib for cross head.
60. Upper brass gib for cross head.
61. Taper steel key (for piston rod).
62. Brass boxes for wrist pin.
63. Adjusting screw for wrist pin boxes.
64. Finished tap bolt for cylinder cover.
65. Main plunger of dash-pot.
66. Engine crank.
67. Crank shaft.
68. Top box for a main pillow block.
69. Lower removable box for main pillow box.
70. Quarter boxes for main pillow block.
71. Parallel pieces for main pillow block.
72. Side wedges for main pillow block.
73. Bolts for holding down main cap.
74. Draw bolts for side wedges.
75. Bull ring.
76. Packing ring.
77. Steel set spring for packing.
78. Follower bolts.
79. Bull ring (end view).
80. Follower.
81. Piston head.
82. Lock for piston packing.
83. Compound cup for main bearing.
84. Cross heads for plunger rods.
85. Plunger rods.
86. Stationary plunger.
87. Top air valve.
88. Bottom air valve.
89. Flange for wrist plate stud.
90. Taper stud for wrist plate.
91. Brass sleeve babbitted.
92. Brass sleeve collar.
93. Valve rod pins.
94. Blow block.
95. Hook pin thimble.
96. Hook pin.
97. Collar for hook pin.
98. Starting bar.

38 in., the stroke of each being 60 in. Neither cylinder is steam-jacketed, and the steam passes into a receiver before it enters the low-pressure cylinder. The volume of this receiver is about equal to that of the low-pressure cylinder.

The cut-off gear of the high-pressure cylinder is under the control of

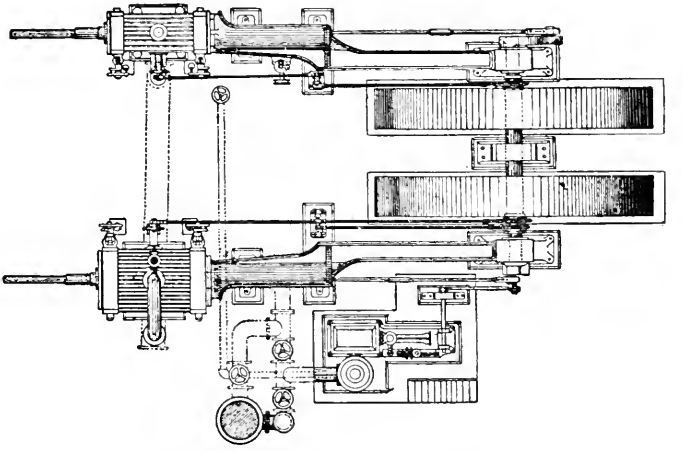


FIG. 37.—COMPOUND TWIN CORLISS ENGINE. WITH RECEIVER, CONDENSER, AND HEATER PLAN.

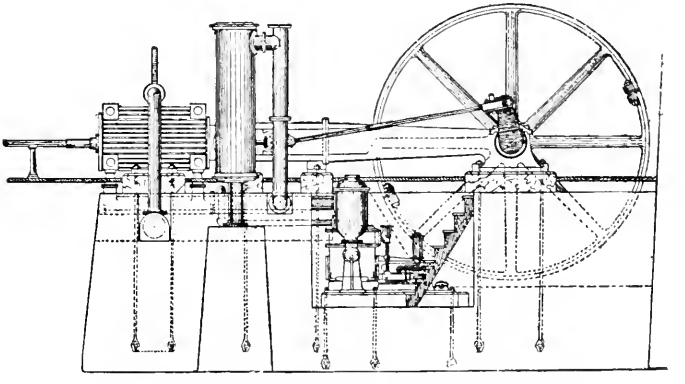


FIG. 38.—ELEVATION OF TWIN COMPOUND CORLISS ENGINE.

the governor, while that of the low-pressure is adjustable by hand, enabling the engineer to set it to cut off at the point shown to be most advantageous by the indicator diagram.

The engine frames are of the well-known girder type, and the piston-rods extend through the back cylinder-head, and are supported on suitable

guides, thus relieving the lower part of the internal surface of the cylinder of considerable weight and friction.

The feed-water heater and condenser are placed outside the engine on the low-pressure side, as shown in the plan (fig. 37). The air-pump is driven by means of a connecting rod to the crank-pin.

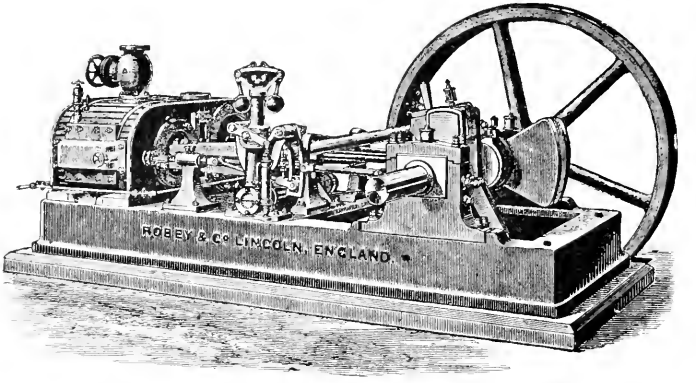


Fig. 39.—Robey's Compound Mill Engine.

The following are the leading dimensions:

Diameter of high-pressure cylinder	22 in.
Diameter of low-pressure cylinder	38 ,,
Stroke of both	60 ,,
Diameter of air-pump (double acting)	15 ,,
Stroke of air-pump	20 ,,
Diameter of feed pump plunger	4 ,,
Stroke of feed pump plunger	12 ,,
Diameter of steam pipe to high-pressure cylinder	7 ,,
Diameter of exhaust pipe to condenser	12 ,,
Atmospheric pressure (about)	11 lb.
Boiler gauge pressure	70 ,,
Temperature of injection water	78 degs.
Temperature of hot well	110 ,,
Revolutions per minute	56 ,,
Indicated H.P. of high-pressure cylinder	161 H.P.
Indicated H.P. of low-pressure cylinder	171 ,,
Total indicated H.P.	332 ,,

For the purpose of driving large mills some such an engine as the Corliss is undoubtedly the best. Where a smaller power is required some form of compound engine, such as that illustrated in fig. 39, is much used, either with or without a condenser, according to the abundance of the water supply.

The engine illustrated is one of Robey's new pattern compound fixed

engines, which has been specially designed for use when a large power is required in a limited space.

The engine is erected on a massive cast iron bed-plate, which gives it great stability. The crank bearings and all other working parts are of great size, thus allowing of smooth and cool running, and materially reducing the wear and tear.

These engines will run at comparatively high speed, and are fitted with an expansion governor, which controls automatically the point of cut-off in the high-pressure cylinder, and allows of variations being made in the load without perceptibly affecting the speed of the engine.

It is stated that the economy of fuel resulting from the use of these engines is very great, a large number of tests proving that less than 20 lb. steam (= 2 lb. coal) are required to develop 1 horse-power; thus 50 horse-power can be obtained from less than $\frac{1}{2}$ ton of coals per day of 10 hours. If there is sufficient water to allow of the use of a condenser a still greater economy of fuel may be attained to

These engines are made in sizes varying from 80 to 50 horse-power and the following list will give the approximate prices of the engines and boilers suitable for feeding them with steam:

Nominal Horse-power.	Engine.	Extra for Jet Condenser if required.	Extra for Force Pump.	Extra for Foundation Bolts.	Boiler and Fittings.	Extra far Injector, if required.
	£	£	£	£ s.	£	£
8	170	30	5	2 10	135	8
10	190	30	5	2 10	145	8
12	210	40	8	2 10	157	8
16	248	50	10	4 10	192	10
20	285	60	10	5 0	235	10
25	345	75	10	5 10	295	15
30	400	80	15	5 10	345	15
40	585	90	15	7 10	480	15
50	705	105	20	8 10	540	18

In many cases the locomotive type of boiler with engine underneath, such as is shown in figs. 46 and 47, with winding drums attached, is used for driving small mills. The usual practice now, however, is to employ a compound engine, such as the one described, and a detached locomotive multitubular boiler where powers under 50 horse-power are needed. Above that it is better to put down a permanent plant of Corliss engines and Lancashire boilers, especially if there are no great difficulties of transport to contend with.

The use of water-power for driving mills is described in Chapter I., and electricity as a motive power is dealt with in Chapter XXVII.

Priestman's Oil Engine.—The ordinary form of gas engine cannot often be employed in connection with metalliferous mines, as these are usually suited far away from any source of gas. A new motor, however, has recently come into the market which can, I think, be utilised for the purposes of pumping, winding, and hauling, with as great advantage in metal mining as it has already met with in collieries for like purposes. This is the oil engine, patented and manufactured by Messrs. Priestman Bros., Limited, of Hull, which is constructed in all convenient sizes up to 25 horse-power; and, as it will be a novelty to some of my readers, I will give a somewhat full description of it. Those of them who may wish for yet further particulars may be referred to the "Proceedings" of the Institution of Civil Engineers for March 8th, 1892, for the more complete details which they will there find in a paper by Professor W. C. Unwin, F.R.S., on the subject.

Referring to fig. 40, which is a sectional view of the engine, z is the working cylinder; x is the piston; K the clearance space into which the air and vapour are compressed before explosion. At Y is the supply tank for oil. In order to deliver the oil from this tank to the spray-maker (S) or starting lamps (EE) an air pressure is maintained in the tank, which is produced initially by the small hand-pump (M), and afterwards maintained by an air-pump, driven by an eccentric. A spring loaded safety-valve on the oil tank keeps the air pressure constant, and this is indicated by a gauge fixed on the tank. There is also a glass gauge to show the oil level in the tank. O is the vaporising chamber, provided with a jacket through which the hot exhaust passes. The lamps (EE) are used in heating the vaporiser initially, and are supplied with oil and air from the oil tank (Y). The oil tank has a sixway cock (A) arranged very simply. When the handle is upright the cock is closed; when turned to the left, air and oil are supplied to the starting lamps (EE); when turned to the right they are sent to the spray-maker (S). The engine cylinder is water-jacketed, the water being circulated either by gravitation from a tank or by a special pump on the engine. At the back of the cylinder, are two valves, one being automatic and the other opened by an eccentric. The upper or automatic valve (T) opens on the suction stroke, admitting the mixed air and vapour from the vaporiser.

The lower valve (T′) is opened during the exhaust stroke (not during the compression stroke) by an eccentric on a shaft rotating half as fast as the crank-shaft. Through this valve the exhaust gases pass to the jacket of the vaporiser. At the back of the engine are shown the bichromate battery and induction coil used for igniting the charge. The circuit is completed at the proper moment by a contact finger on the eccentric rod, which passes between a pair of springs. A screw plug (K) in the side of the cylinder contains two porcelain bars, through which the electric wire passes. The electrodes in the cylinder are platinum wires.

In starting the engine the oil tank is put under pressure by the air-pump, and the lamp lighted. When the vaporiser is hot enough, which

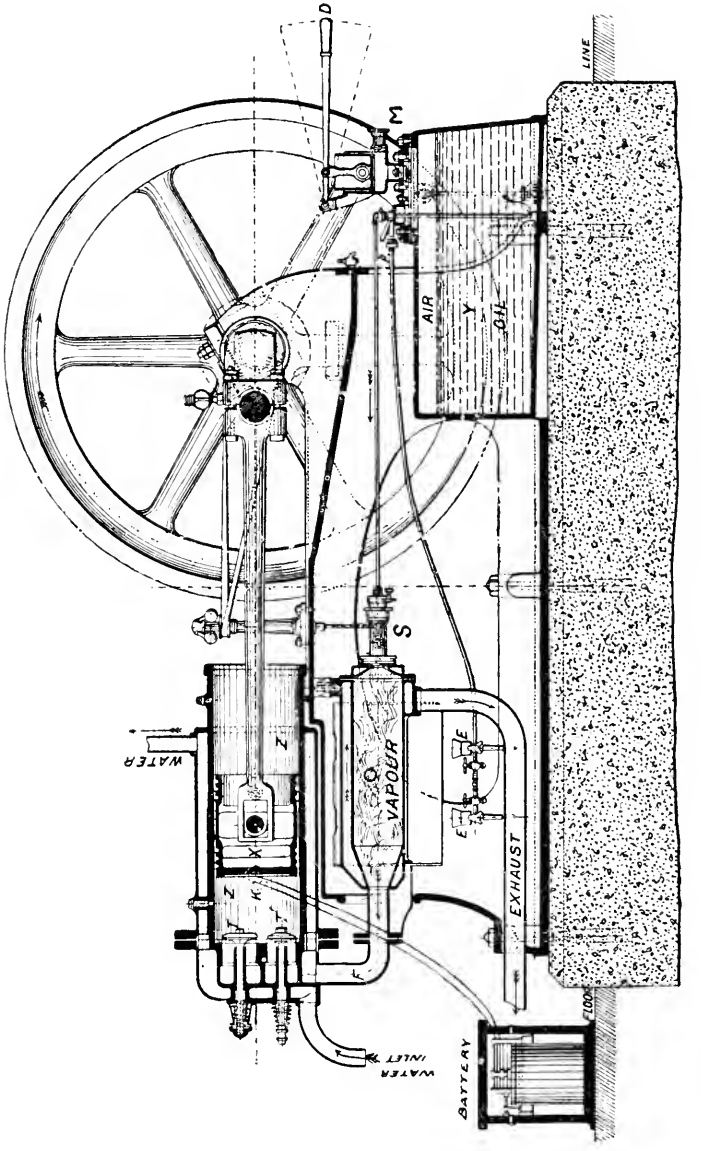


FIG. 40.—SECTION OF PRIESTMAN'S OIL ENGINE.

will be in from eight to twenty-five minutes, according to the size of the engine, the sixway cock is opened to admit oil and air to the vaporiser.

The flywheel is then turned, the engine draws in the explosive mixture, compresses it, and starts. The action is that the explosive mixture is drawn in during a suction stroke, compressed in the return stroke, ignited at the moment of full compression, and the working stroke effected by the expansion. The next return stroke drives the products of combustion through the exhaust valve and around the jacket of the vaporising chamber, which is thus heated.

During the compression stroke a small portion of oil condenses inside the cylinder, which it thus perfectly lubricates, rendering all other lubrication unnecessary.

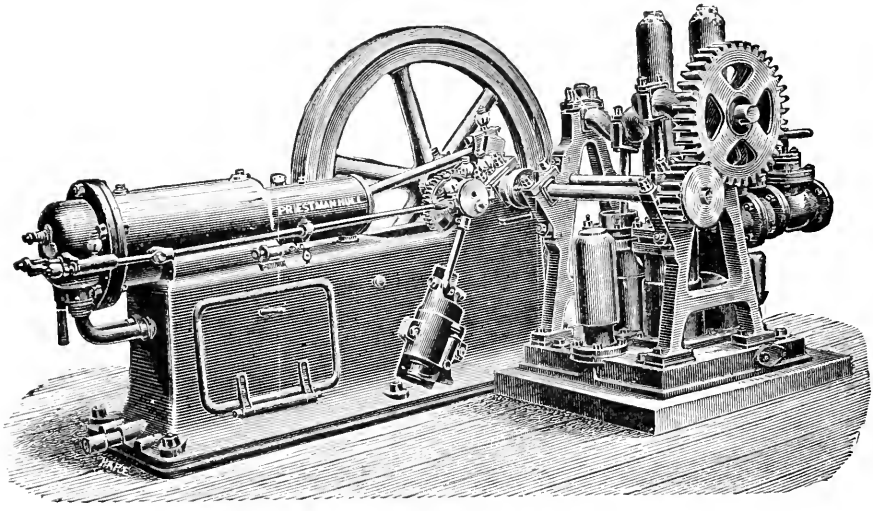


Fig. 41.—Priestman's Oil Engine coupled to a Three-Throw Pump.

The ignition of the compressed oil vapour is effected by means of a spark between platinum points at K, which are connected by two insulated wires with the battery box or igniter. A bichromate cell and induction coil have been found by Messrs. Priestman to be the best practical means of providing the electricity; and they claim that their battery will keep in work from 30 to 40 hours at a cost of under 4*d.*—or say, 1*d.* per day.

As to the practical results of running this engine, and the cost in comparison with steam or gas, it is stated by the manager of the Teesdale Mineral Company that an 18 horse-power oil engine supplied to his works for the purpose of driving a grinding mill for barytes has been most satisfactory, and has cost about 2*d.* per horse-power per hour.

In that district the comparative cost of various motors is stated to be as follows:

Steam Engine. 20 H.P., working 10 hours per day.
,, 10 ,, 24 ,, ,,
Cost of coals, £100 per month = 2*d.* per H.P. per hour.
Driver's wages, about $5\frac{1}{2}d.$ per hour.
Lubricating oil, say 3*d.* per hour.

Gas Engine. 6 H.P. 400 cubic ft. of gas per hour at 4*s.* 8*d.* per 1000 = $3\frac{3}{4}d.$ per H.P. per hour.
Lubricating oil, say $1\frac{1}{2}d.$ per hour.

Oil Engine. 18 H.P.
1 pint of oil per H.P. per hour at 8*d.* per gallon = 2*d.* per H.P. per hour.
Lubricating oil, 1*d.* per hour.

The oil used is refined petroleum, the same as that employed in the domestic lamp, and sold everywhere under a variety of names—such as Royal Daylight, Russian, Water White, Scotch Paraffin, etc. The chemicals required for the battery are sulphuric acid, bichromate of potash, and zinc plates. Very small quantities, however, are used. For a run of from 20 hours to 30 hours, 8 oz. of bichromate and 6 oz. of sulphuric acid is ample, while the zinc consumed during that time can be neglected.

For districts where fuel and water are scarce an engine of this class is especially suitable, seeing that petroleum can be procured and transported with ease, the more so as the quantity consumed—a pint per horse-power per hour—is but small.

As with gas engines, so with the oil engine: it is impossible to stop frequently or reverse the motor, so that for hauling or winding purposes a friction clutch must be used. Fig. 41 shows one of these motors applied to a three-throw pump. They are also used for driving dynamos, which is in itself a testimony to the uniformity of the speed. This on all of them is controlled by a special governor.

These engines have also been mounted on a truck and attached to a rotary drill, and have also been used for driving air compressors. The advantage in this case is that the engine and compressor can be erected close up to the drills, by which means the long length of piping often required between the drills and the compressing plant is avoided, and a considerable economy thus effected.

An example of the use of petroleum engines may be found at the Clogau Mine of the St. David's Gold and Copper Co., Limited, in Merionethshire, North Wales, where a small petroleum engine is in use driving an air compressor, and another one inside the mine for winding and pumping. The disadvantage of this latter is the smell created, which, before special ventilation pipes were inserted, was insupportable.

The 50-stamp mill at the same mine is driven by a Pelton wheel when there is sufficient water. In addition to this, and in reserve for dry seasons, a 150 horse-power Crossley gas engine has been erected, the gas being

made on the spot from a producer. The fuel consumption is one pound of Welsh anthracite coal per horse-power per hour.

The Union Hoisting Engine.—Gas engines for mining purposes are much in use in the United States. In fig. 42 will be seen an illustration of a "Union" hoisting engine, which consists of a double

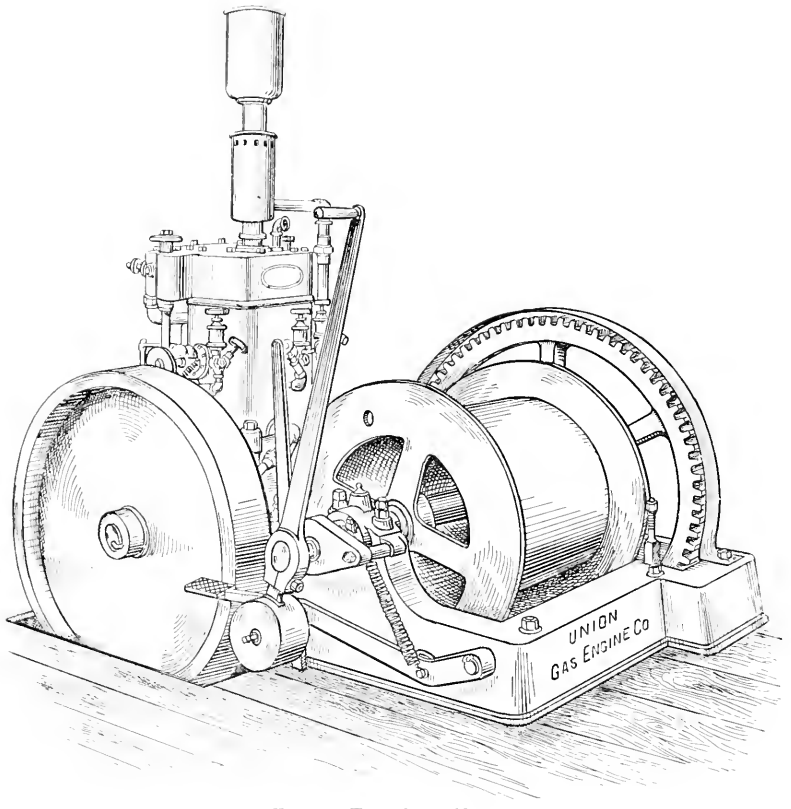


FIG. 42.—THE UNION HOIST.

cylinder vertical engine and hoist combined. The engine runs on gasoline, naphtha, or benzine, and if ordinary gas is handy can be adapted for that also. The engine in the illustration is 10 horse-power, and will lift one ton 125 ft. per minute from a maximum depth of 500 ft. These engines are made in sizes from 4 horse-power to 50 horse-power, by the Union Gas Engine Company, of San Francisco.

A difficulty in the use of gas or petroleum engines arises from the fact that the engine must be kept constantly running and cannot be

stopped and started at will like a steam engine. For use therefore for intermittent purposes, clutch or friction gearing are necessary, and many satisfactory devices have been designed for this purpose by both home and foreign manufacturers. At the Cwmystwith Mines, in North Wales, there is a gas plant in reserve for driving the mill, and the gas used is "water gas" made on the spot.

Gas Producers.—It is evident that, since mining operations are rarely if ever conducted in the neighbourhood of a gas supply, some form of gas producer must be erected near the mine.

The only producer with which I am acquainted is that made by the

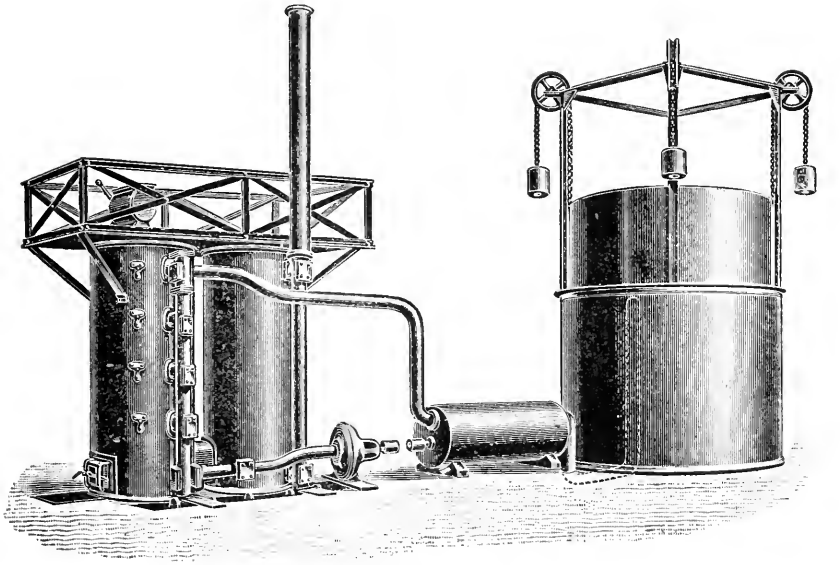


FIG. 42A.—GENERAL VIEW OF GAS PRODUCER.

Industrial Engineering Company, of Newton, near Hyde, Cheshire, of which the following is a description, and which has the advantage of working either with sawdust, waste wood, coke, or coal, as a fuel, the latter even when of a most bituminous nature.

The general arrangement of this gas producer plant is shown in fig. 42A, which, shows from left to right the generator with feeder hopper on top, the regenerator with chimney, fan for blowing air, gas washer, and gas holder from which a pipe is taken in the usual way for connection with the gas engines. The interior arrangements of the generator and regenerator are shown in fig. 42B, and the exterior valves and connections in figs. 42C and 42D.

The generator or producer (*a*), figs. 42B, 42C, 42D, consists of a vertical metal casing (1), thickly lined with firebrick or other suitable refractory material (2), and provided at the top with a hopper (3) for the supply of the fuel to be converted into gas.

The generator (*a*) has in its walls a number of air inlet pipes and passages (4), disposed at different points one above the other, consisting of annular spaces with openings controlled by valves and covers and communicating by radial passages with the interior at different heights, and at different times progressively. There is, also, near the top of the

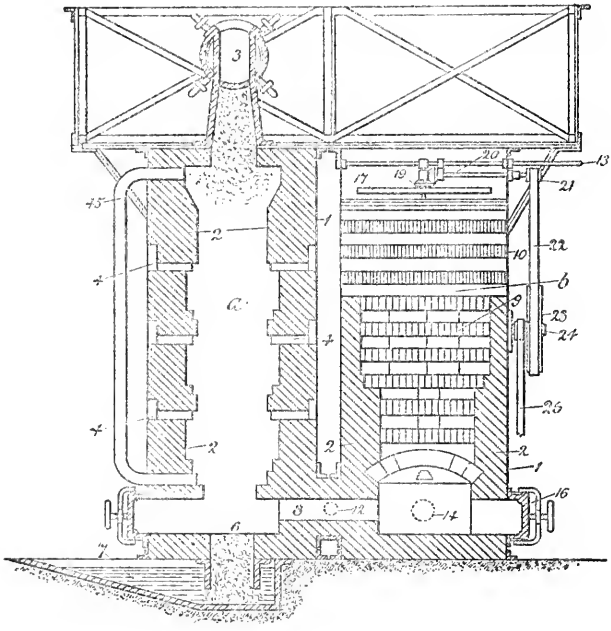


FIG. 42B.—OUTSIDE ELEVATION OF GAS PRODUCER.

generator, an outlet passage and pipe (5), controlled by a valve for the delivery of the gas. It is also fitted with sight holes and other fittings common to similar furnaces, and at its base a fireplace (6) is provided for the initial starting of the apparatus.

At the bottom of the generator there is an outlet through which the ashes fall into an ashpan or trough (7), which is kept nearly full of water in order to seal the outlet and keep the generator gas-tight. The ashes as they fall can be raked out periodically and removed from the ashpan.

The generator is connected at its base by a passage (8) with the base of a regenerator (*b*), consisting of a vertical metal casing (1), thickly lined

with refractory material (2), and partly filled with firebrick checker-work (9), and partly with checker-work of iron (10), or other material not liable to disintegrate under the action of moisture and heat. At its upper end the regenerator (*b*) is connected with a chimney (11), which is opened and closed by a valve, and at some suitable point in the regenerator, preferably near the base, is an air-inlet pipe and passage (12) fitted with a valve in a casing (13), and a scavenging outlet (14), fitted with a valve in a casing (15). The regenerator has also sight holes (not shown) for enabling its interior to be inspected and a suitable door (16) for cleaning purposes.

In the regenerator, above the iron checker-work (10), is mounted a revolving distributer (17) supplied with water as required through a pipe (18), controlled by a tap or valve (not shown). The distributer (17) is revolved by a pair of bevel gears (19) and belt connection with the shaft (28) which is driven in any convenient manner from a gas engine or other suitable motor, and has mounted on it the cams for actuating the several gas and air valves.

When starting the apparatus a little fuel is fed through the hopper (3) into the interior of the generator and a fire is started in the fireplace (6) beneath it, the cleaning and poking orifices being open at the time. As the fuel burns the cleaning and poking orifices are closed and a fresh supply of fuel is gradually fed through the hopper (3) until the whole mass within the interior becomes highly heated. The fresh fuel, owing to the high temperature of the generator, at once volatilises to the extent of giving off a combustible gas which may be allowed to pass off through the gas-outlet pipe (5) to a gas holder, whence it may be conducted to the gas engine and utilised to run the engine for a few turns whilst starting the apparatus.

Then the gas valve (34) is closed, and the outlet valve (44) from the regenerator to the chimney is opened, and the ordinary working of the apparatus now begins; first, air is blown into the generator from the fan shown in fig. 42A, connected to a pipe (46) leading to the pipes and passages (4 and 12). The air passes down through the highly heated mass of fuel first from the highest air inlet (4) and then from the next in order lower down, the valves (38, 39, 40) of the inlets being opened and closed by their respective cams, thereby creating a series of zones of high temperature at different heights which combine to constitute a column of incandescent fuel. During the blowing period as described the gaseous products of combustion pass from the generator (*a*) into the lower extremity of the regenerator (*b*) and in their passage meet a supplementary supply of air admitted by the valve (13) through the air inlet (12) whereby complete combustion is effected. After this the gaseous products ascend up the interior of the regenerator, first through the firebrick checker-work (9) and then through the iron checker-work (10), which absorb the heat from the products before they escape up the chimney. When the

regenerator has become highly heated the blowing period is terminated and all the air valves (38, 39, 40, and 13) are closed as well as the valve (44) controlling the outlet to the chimney (11).

The scavenging valve (15) is then opened and the tap or valve of the water supply is also opened automatically by means of a cam and connections, so that water is sprayed upon the heated iron checker-work (10) and is instantly converted into steam which passes downwards through the interior of the regenerator and displacing the remnant of combustion

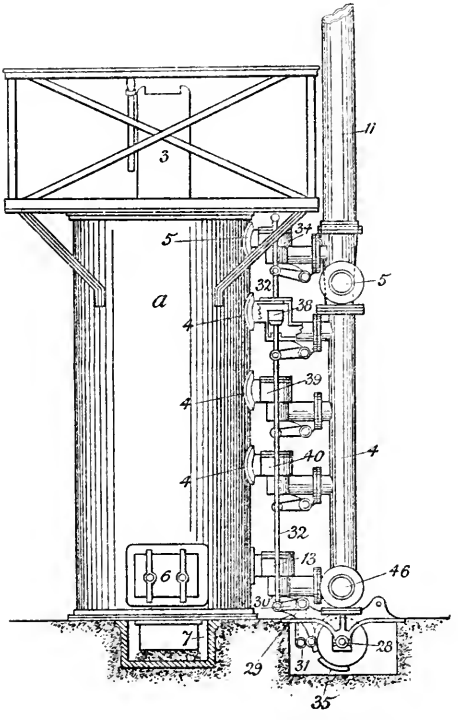


FIG. 42C.—SECTION OF GAS PRODUCER.

products therein, scours them out through the scavenging opening (14). The scavenging valve (15) is only open for a very brief period, and immediately it is closed the gas outlet valve (34) of the generator is opened.

The steam now superheated passes along the passage (8) up through the column of incandescent fuel in the generator, and in so doing becomes decomposed into its constituents, hydrogen, carbonic oxide, and other gases being produced. The gases now pass up through the green or raw fuel at the top of the generator and subject it to destructive distilla-

tion, the hydrocarbon and other vapour thereby liberated mixing with the gases and passing away with them through the gas outlet pipe (5) to the gas holder.

To facilitate combustion and prevent caking or clinkering of such fuel in the generator (*a*) as has that tendency, a smoke pipe or passage (45), controlled by a valve, may be employed leading from the upper part to the lower part of the generator. The effect of this pipe or passage is

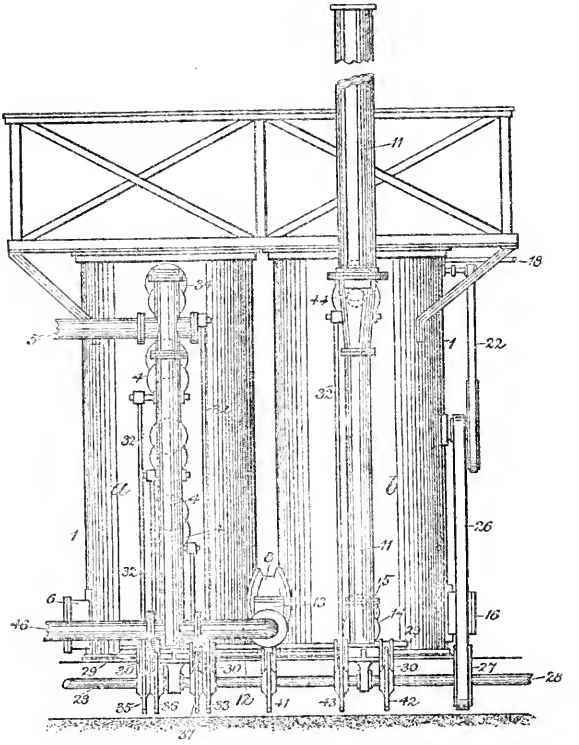


FIG. 42D.—SECTION OF GAS PRODUCER.

by providing an outlet in the upper part of the generator to cause an up draught of part of the blast introduced through the air inlet passages.

On the termination of the gas-making period the blowing period in the generator recommences. Thus it will be seen that water gas is first formed, and then is converted into a richer gas by its passage through and its action upon the green or raw fuel.

As already stated, the apparatus may be operated by any convenient motor, and if a gas engine be employed, the gas producing plant is intended to make the gas necessary for the engine, and this engine will,

through the shafts, cams, and connecting mechanism, effect the automatic working of the apparatus.

The gas obtained by this producer is of a very high calorific power, resulting from its being enriched with the natural hydrocarbon of the coal used, and has a value in British thermal units of from 380 to 400, as compared with the 145 to 150 British thermal units, obtained in the ordinary style of producer. This high calorific power is partly due to the comparative absence of nitrogen in the gas as is shown in the following analysis :

Carbonic Oxide	37 %
Carbonic Acid	3 %
Hydrogen	42 %
Hydrocarbon	10 %
Nitrogen, Sulphuretted Hydrogen, etc.	8 %

Doubtless the fact that the introduction of air is stopped before the making of gas commences, so that the waste products of combustion are not introduced into the gas accounts for the small percentage of nitrogen in this as compared with other producer gas. It will be noticed also that the waste heat of combustion is used to create the steam which is not the case in other producers.

An important point is that almost any fuel can be used; while at the time I saw the plant at work, common bituminous engine slack, which sells at the pits at from *2s. 6d.* to *3s.* per ton, was employed. The consumption of this gas in a good gas engine is from 20 to 25 cubic ft. per brake horse power per hour, while the fuel used is about 1 lb. per horse power per hour.

The simplicity of this apparatus and its high efficiency will make it valued as a gas producer either for power or heat purposes. For lighting this gas would require enriching, but in its present form it can be used with incandescent burners. The apparatus is so simple that the ordinary mining labourer can soon be taught to manage a plant, which once set going requires little further attention, owing to its automatic nature, beyond being fed at regular intervals with fuel.

CHAPTER IV.

HOISTING MACHINERY.

The Horse Whim—Horse-power Hoister—Portable Winding Plant—Semi-Portable Winding Engine—Single Cylinder Winding Engine with two Drums—Double Cylinder Winding Engine, on Girder Frame—Permanent Winding Engines—Geared Hoisting Engine, American Type—Pit Head Gear—Wooden and Iron Frames—The Cage—Keeps or Landing Dogs—Hoisting Plant for Inclined Shafts—Skips—Loading and Unloading Skips.

THE preliminary work at the commencement of the working of a shaft is usually done by means of a wooden jack-roll, or a winch. The depth of the pit and the quantity of rock to be extracted soon, however, become too great for this simple contrivance; and so, if funds are scarce, and an engine is out of the question, the local carpenter is called in, and a horse-whim is constructed on the lines of that shown in fig. 43, which is the type adopted in Cornwall and Wales.

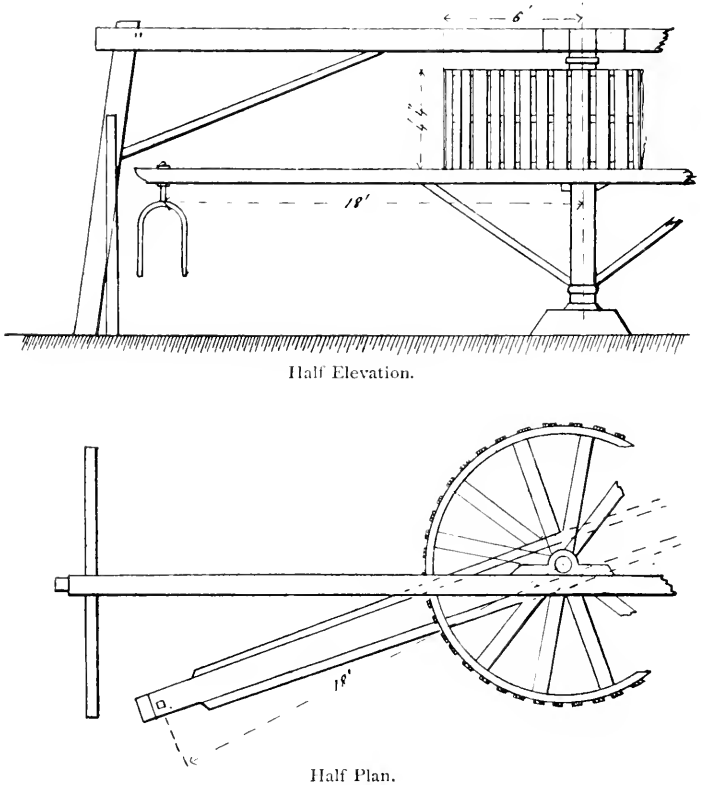
The construction will be gathered from the drawing, which is to a scale of $\frac{1}{8}$ in. = 1 ft. The diameter of the drum is 12 ft., and that of the horse track 36 ft.; so that, in order to attain a winding speed of 100 ft. per minute, the horse or horses, if the depth is greater than 50 yds., will have to walk at a rate of $3\frac{1}{2}$ miles per hour. This speed will be found too great for the ancient animals usually employed, and a speed of about 75 ft. per minute in the shaft will be about the average. The framing over the pit carries two pulleys, of from 18 in. to 2 ft. in diameter, the top of each pulley being on a line with the centre of the lower and upper halves of the drum respectively. A hemp rope is employed, and the total load is from 2 to $2\frac{1}{2}$ cwt.

The simplicity of the horse-whim has caused it to be used extensively. The materials are generally to be found in mining districts, and it can be made in a rough-and-ready fashion by an ordinary carpenter.

Horse-power Hoister.—The old-fashioned wooden horse-whim already described is a capital piece of temporary machinery, and for mines in out-of-the-way places is about the only means by which prospecting working operations can be carried on to any depth. It

is, however, bulky, and, if the trial is unsuccessful, is somewhat difficult to pull down and transport; indeed, the number of these old whims which may be seen in some mining districts would lead one to believe that they are not worth removal.

A small hoisting plant for horse-power has been designed, and is largely used in America, for the purpose of overcoming the inconveniences of the old horse-whim, and is illustrated in fig. 44. It



Half Elevation.

Half Plan.

FIG. 43.—THE HORSE WHIM. ¾ IN. = 1 FT.

consists of a drum (*a*) driven by means of the gearing (*c*). A square wooden pole is fitted into the socket (*b*) to the further end of which a horse is harnessed, and travels in a circular path. The drum is fitted with a powerful strap brake (*d*) and a disconnecting clutch.

The horse travels in one direction only during the hoisting. For lowering the drum is thrown out of gear, and controlled by means of the brake.

The winding rope is carried along the ground until clear of the horse, when it passes under a pulley, and then up the pit frame, and over the main winding pulley.

The brake and disconnecting levers are placed close to the pit frame, so as to be conveniently handy to the banksman.

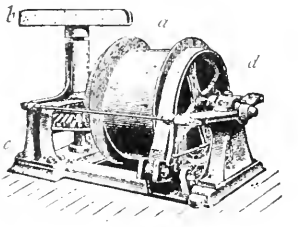


Fig. 44.—Horse-Power Hoister.

These hoisters are intended for temporary purposes only, but will carry on the sinking operations down to 300 ft. The total load, including the ore and bucket, should not exceed from 800 lb. to 1000 lb., and the speed will vary from 75 ft. to 60 ft. per minute, according to the weight.

Portable Winding Plant.—During the preliminary prospecting period, through which a mine must pass before its value is sufficiently established to warrant the erection of permanent machinery, a small portable hoisting plant is of the greatest utility.

Plant of this kind (illustrated in fig. 45) has been designed by

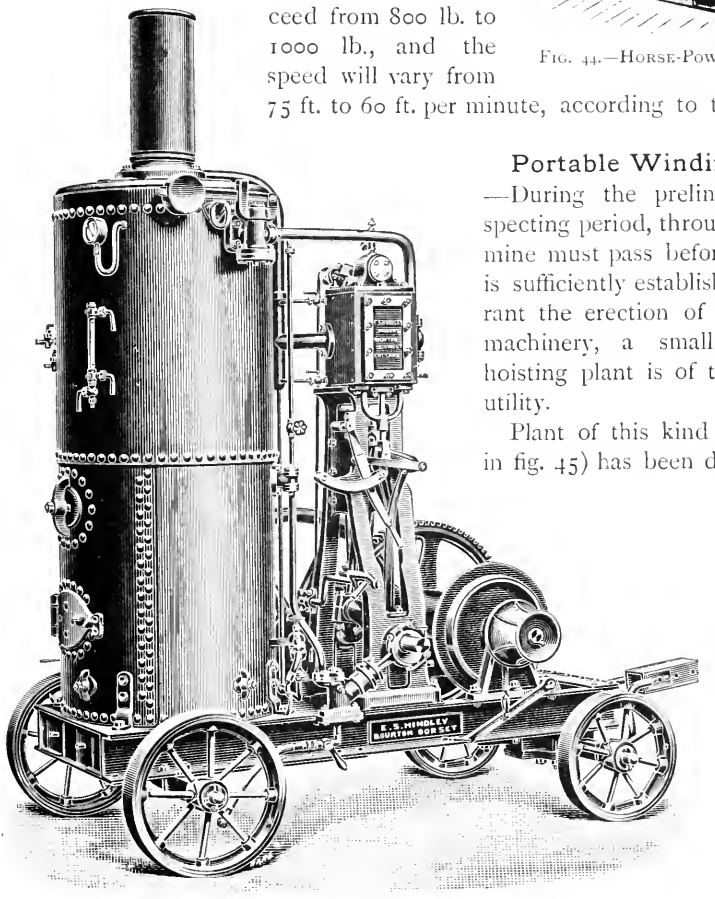


Fig. 45.—Portable Winding Plant.

Messrs. E. S. Hindley & Sons, of Bourton, Dorset, with the special view

of supplying a hauling, hoisting, or power plant on a small scale, which is not only portable, but is so constructed as to withstand the rough treatment which it assuredly would receive from unskilled hands.

It consists of a vertical engine, with a vertical cross-tube, or other type of boiler mounted on a strong wrought iron girder plate, extended forward so as to carry the winding drum, which is geared to the crank shaft. The engine is fitted with reversing gear. The drum has a powerful brake, which may be either single or double cylinder, controlled by a foot lever, and can be unclutched from its shaft. The engine can then be used for driving a saw bench, or a few head of stamps or other machinery, in view of which a turned flywheel is keyed to the engine shaft, from which a belt may be taken to the other machines. The starting and reversing handles, the clutch lever, and the brake foot lever, are all brought together, so as to be well within the reach of the driver.

The engines are made in several sizes, varying from 2 to 8 horse-power. The 2 horse-power is capable of lifting a load of 8 cwt. at a speed of 93 ft. per minute, and the 8 horse-power a load of 30 cwt., at a speed of 65 ft. per minute.

For prospecting purposes engines of this type are exceedingly useful, as they can be readily removed from one shaft to another, as the work progresses and the results of sinking prove satisfactory or otherwise. It would evidently be unwise to erect a permanent winding plant until the ore bodies are absolutely proved in length and depth, although this has been done on too many occasions with disastrous results, involving ruin to the companies and their shareholders. For the preliminary operations of exploring and prospecting, small hoisting engines of the type under notice, which involve no large expenditure of capital, are well adapted for the work required.

Semi-portable Winding Engines.—As the chances of failure in metalliferous mining are generally supposed to be greater than those encountered in collieries, and also as the weight to be raised per day is usually less in the former than in the latter case, it often happens that the hoisting machinery is of a more temporary character than that provided for raising coal.

The necessity also of providing such machinery as can be readily transported over mountainous country has led to the introduction and extended use of winding engines of the "semi-portable" type, such as those illustrated in figs. 46 and 47, which are manufactured by Messrs. Robey, of Lincoln, in sizes of from 4 to 200 actual horse-power.

The boiler is of the locomotive multitubular type, with an iron chimney, which receives the exhaust from the engines, thus creating a powerful draught, and so admitting the use of inferior fuel. It is mounted with all the usual fittings, and the driving handles, brake levers, and

clutches are all so arranged as to allow of the engine being attended to by one man only.

Formerly the engines were mounted on top of the boiler, but this type is now obsolete, and they are placed underneath, being mounted

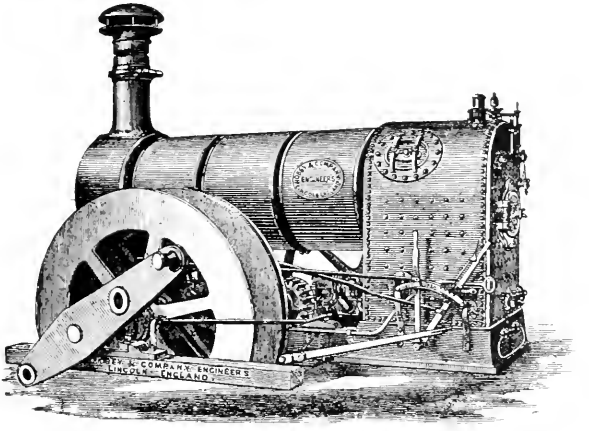


Fig. 46.—Robey Semi-Portable Winding Engine (Side View).

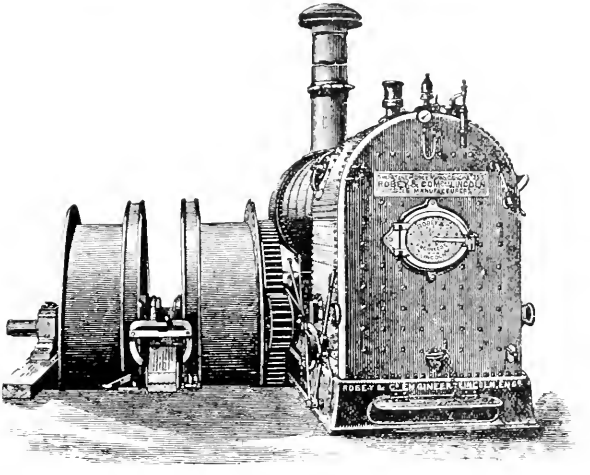


Fig. 47.—Robey Semi-Portable Winding Engine (Front View).

on a cast iron bed plate, which has also suitable bearings for receiving the pumping and winding shafts, brake shafts, and levers, so that the boiler is relieved from all strain due to the engine. The crank shaft carries a heavy flywheel at one end, and a pinion wheel at the other, which gears into the spurwheel on the drum shaft. The weight of the

full boiler greatly helps to steady the engine, and consequently reduces the amount of foundations necessary.

The cylinders are steam jacketed, fitted with link motion reversing gear, and are so arranged that a portion of the exhaust is directed into the feed-water tank, which is in the base plate underneath he cylinders. It is claimed that, owing to the many improvements made in this engine, an economy of fuel of from 10 to 50 per cent. is effected over the old type.

As the boiler fits over the engine, and is not permanently connected with it, the engine can be obtained separately, and driven from any existing boilers; or the boiler and engine can be mounted apart in places where it is inconvenient to have them combined on the same base plate, as in fig. 47.

A crank is fixed at the end of the drum shaft, to which the pump rods may be attached, and the drums are each supplied with a disconnecting clutch, so that they may be used separately, or entirely disconnected when the engine is required for pumping only.

These engines are well adapted for raising the heavy loads customary in metalliferous mines, at a comparatively low rate of speed—say, of from 400 ft. to 500 ft. per minute.

They are much steadier than the older type with the engines mounted on the boiler, and if care is taken to give them a firm foundation, they will fulfil all the purposes of a permanent "plant," which may or may not be substituted when the production and development of the mine warrant the outlay.

In order to get over the difficulty of a brick or stone foundation in those parts of the world where building materials are scarce, Messrs. Robey have designed an engine which will practically work without foundation. The engine, boiler, and gearing are the same as those already described, but are mounted on a wrought iron tank a yard or more in depth.

In fixing the engine, it is only necessary to make an excavation in the ground of suitable size to receive the wrought iron tank, which can then be filled with earth or sand, and so form a firm and secure foundation. For transport, the loose fittings of the engine are packed in the tanks, which is a convenient mode of storage.

By removing the winding gear, and adding a belt pulley in place of the pinion, this class of engine is converted into one suitable for driving a concentration mill, and is indeed largely used for that purpose. For milling purposes, however, it is more usual, for convenience' sake, to separate the engine and boiler in the design and construction of the building.

Passing on now to winding engines of a more permanent type, we have in fig. 48 the illustration of a very simple form of winding engine, consisting of a single cylinder, horizontal, fixed engine, driving two drums,

both of them loose on the drum shaft, but capable of being thrown in or out of gear by means of the clutches and levers. This plan of

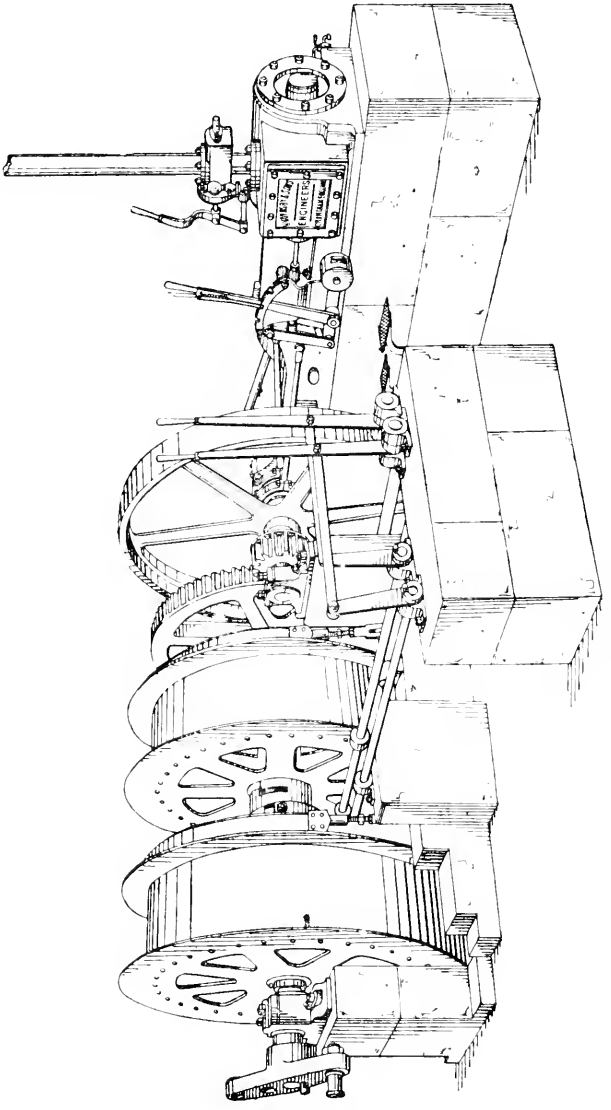


Fig. 48.—Single Cylinder Winding and Pumping Engine.

winding or hauling engine can be used for working two pits or inclines at the same time, as each drum can be employed independently by putting it in or out of gear, and controlling it by its own brake. A

pump crank is also fitted to the end of the drum shaft, so that the engine may be used for winding and pumping either at the same time or separately.

These engines are commonly made in the following sizes, and are capable of doing the work mentioned below:

Size	1	2	3	4	5	6
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
Diameter of drum barrel	2 6	3 0	3 6	4 0	4 6	5 0
Diameter of drum over cheeks ...	3 10	4 8	5 2	5 8	6 6	7 0
Depth of cheeks	0 8	0 10	0 10	0 10	1 0	1 0
Width of drum, plans Nos. 1 and 2	1 8	2 0	2 2	2 2	2 4	2 4
Width of each drum plan No. 4, and each division, plan 1A and 2A	0 10	1 0	1 1	1 1	1 2	1 2
Nominal H.P. of steam engines, suitable for use with the above winding drums, say	4 to 10	6 to 16	12 to 20	16 to 25	20 to 30	30 to 40

For each nominal H.P. of the engine used, the load lifted vertically will be about 2 cwt. at a speed of 250 to 300 ft. per minute.

If hauled up an incline 1 in 5 ... 8 cwt. at a speed of 250 to 300 ft. per minute
,, ,, 1 ,, 10 ... 16 ,, ,, ,, ,,
,, ,, 1 ,, 50 ... 80 ,, ,, ,, ,,
,, ,, 1 ,, 100 ... 160 ,, ,, ,, ,,

The gearing can, however, be arranged, if desired, to lift or haul heavier loads at slower speed, or lighter loads at a quicker speed.

A compact light form of winding or hauling engine for comparatively small power is shown in fig. 49. The engines and drum are mounted

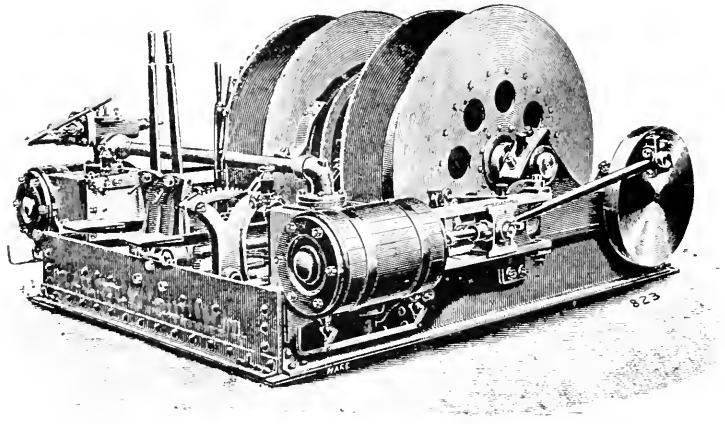


Fig. 49.—Double Cylinder Winding Engine on Iron Girder Frame.

on a wrought iron girder frame, the engine shaft being on the further side of the drum shaft, so that the drums are completely within the

engine frame; thus economising space, but preventing the use of a pump crank on the drum shaft.

These engines are supplied either with two separate drums fitted with clutches and brakes, or with one drum keyed to the shaft and having a division plate in the middle. They are somewhat cheaper than the ordinary form of winding engine, and are largely used either for hauling purposes at large mines or for winding purposes at small ones.

The following are their general dimensions:

	Nominal Horse-power.									
	10		16		20		25		30	
	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.
Diameter of cylinder	0	$7\frac{1}{2}$	0	$9\frac{1}{2}$	0	$10\frac{1}{2}$	0	$11\frac{1}{2}$	1	$0\frac{1}{2}$
Stroke		12		16		20		20		22
Diameter of drum	3	6	3	6	4	6	4	6	5	0
Diameter of drum over cheeks	5	2	5	2	6	6	6	6	7	0
Depth of drum cheeks		10		10		12		12		12
Width of each drum division		13		13		14		14		15

Permanent Winding Engines.—The form of winding engine shown in outline in figs. 50 and 51, is much approved of in South Africa and other mining districts, and is one which is made by all the leading machinery manufacturers. It has double cylinders, with outside cranks, the crank shaft being geared to the drum shaft, which carries a pair of drums. Each drum is loose on the shaft, and is capable of being clutched to it, and is provided with a brake. There is also a brake on the flywheel.

The whole of the brake and clutch levers, starting and reversing handles, are all brought to the back, so as to be readily handled by one man. The illustrations are from drawings to scale, and show clearly the details of the whole arrangement.

Engines of this type require solid foundations of masonry, and as their use would imply that the mineral wealth of the undertaking was fully established, they should be covered in with a substantial engine house.

Geared Hoisting Engine, American Type.—The hoisting engine shown (on a small scale) in connection with the pit-head frame for an inclined shaft in fig. 58 (p. 92), may be taken as typical of this class of machine as made in America. In the illustration the two flat rope drums are shown in use; for round ropes the engine would of necessity be wider, but the general arrangements would remain the same.

An enlarged view of these engines is given in fig. 52, which is the side elevation, and fig. 53 the plan.

There are two slide-valve engines, with link motion reversing gear

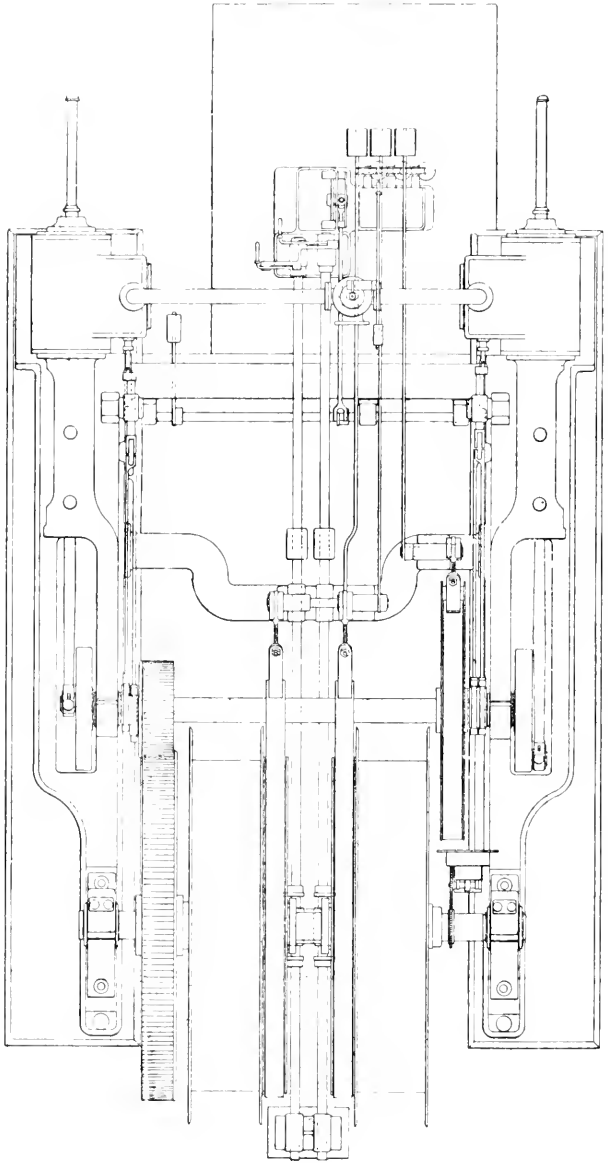


FIG. 50.—35 H.P. COUPLED GEARED WINDING ENGINE FITTED WITH TWO LOOSE DRUMS.

attached, nearly at right angles to the same crank shaft, on which

is a large pinion wheel, which gears into the spur-wheel keyed to the centre of the drum shaft.

The crank shaft is supported in the centre by means of a bearing on each side of the pinion, in addition to those on the engine frame. The drum shaft bearing boxes are made in halves, lined with composition metal, and fitted into planed seats in the cast iron extension pieces of the engine frame, and are secured by substantial caps bolted to the frame.

The drums are independent, run loose on the shaft, and are provided with composition metal bushings, held in place by bolts, admitting of their being readily replaced when worn. The hubs of the drums have a four-toe clutch cast on, and are fitted with substantial clutches, which are so constructed that they can be quickly thrown in under pressure. They are operated by two horizontal shafts with hand levers reaching through the mounting plate. The drum arms are ribbed and lined with hard wood. The brake wheel of each drum is cast separate and keyed to the hub. Each drum is provided with a pair of post brakes lined with hard wood friction blocks, thoroughly braced and fitted with chairs and wrought iron pins on which they oscillate. These brakes are pulled together by adjustable tie-rods at the top, and by means of a bell-crank lever are operated by a wrought iron rack, provided with a hand-wheel, pinion, ratchet and dog. This rack is connected by a strap to a horizontal lever, pivoted in a casting bolted to foundation, and

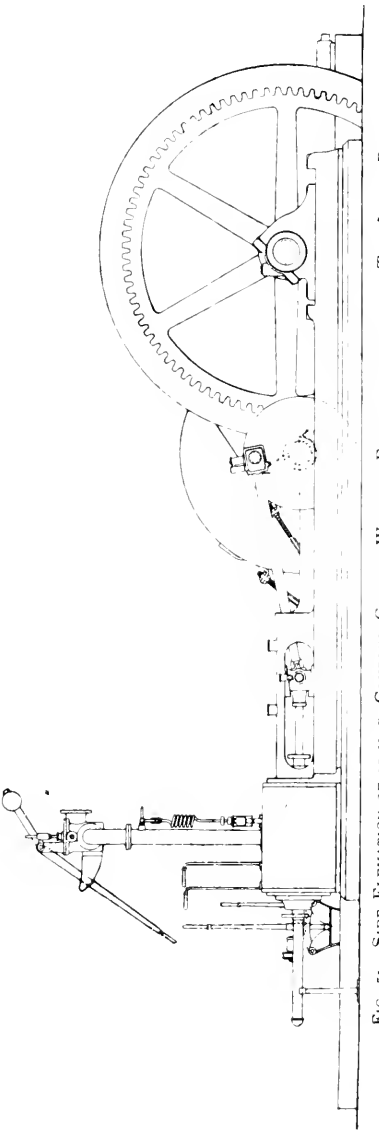


FIG. 51.—SIDE ELEVATION OF 35 H.-P. COUPLED GEARED WINDING ENGINES FITTED WITH TWO LOOSE DRUMS.

which moves a vertical rod operating the bell crank attached to the brakes.

The engine cranks are fitted with hardwood lined strap brakes, operated by one cross shaft, applying the brakes to the discs simultaneously. This shaft is fitted with two foot treadles, as the engineer or attendant stands at one reel or the other, and foot brake must be used in each instance.

For convenience of attaching all levers to one substantial casting, a mounting plate is provided between the cylinders, and is bolted to the foundation at a point where all the levers, including the stop valve

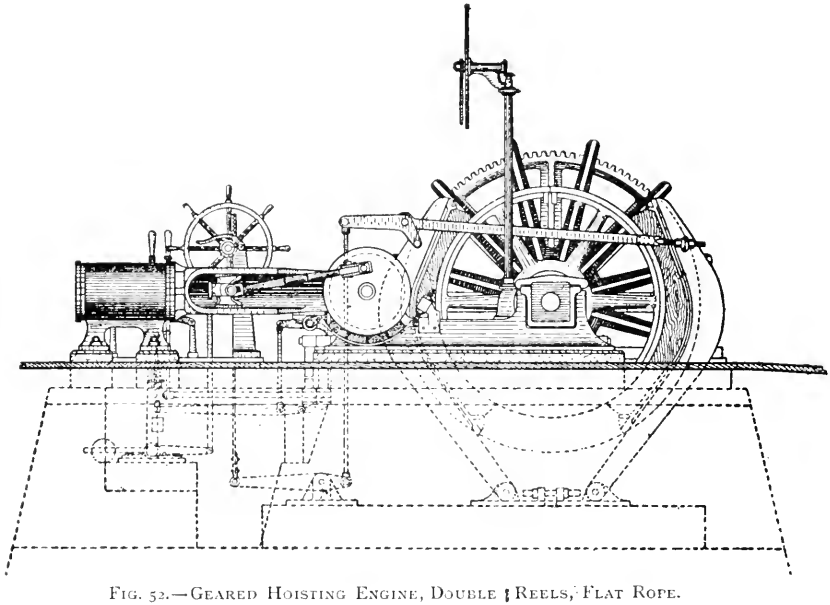


FIG. 52.—GEARED HOISTING ENGINE, DOUBLE REELS, FLAT ROPE.

lever, lever to link with quadrants and standards, rocker shaft and link levers, post brake levers with hand wheels, racks and pinions mounted on stands, clutch levers and foot levers for crank brakes can be reached by the attendant without effort.

An indicator is attached to each drum separately, and the pointer of each is well in view of the driver, so that he can tell the exact position of each step or cage in the shaft.

This class of engine is made in two sizes, one with double cylinders, 10 in. diameter × 16 in. stroke, with drums for a $2\frac{1}{2}$ in. or 3 in. × $\frac{3}{8}$ in. flat wire rope, and designed for vertical depths of 700 or 800 ft., and the other with double cylinders, 12 in. diameter × 16 in. stroke, for a 3 in. or $3\frac{1}{2}$ in. flat wire rope, for vertical lifts of 1000 ft.

An illustration of the use of a petroleum engine for winding purposes will be found in fig. 42 (page 68).

The use of the Pelton waterwheel for hoisting purposes will be found described on page 17, and of electricity for the same purpose in Chapter XXVII.

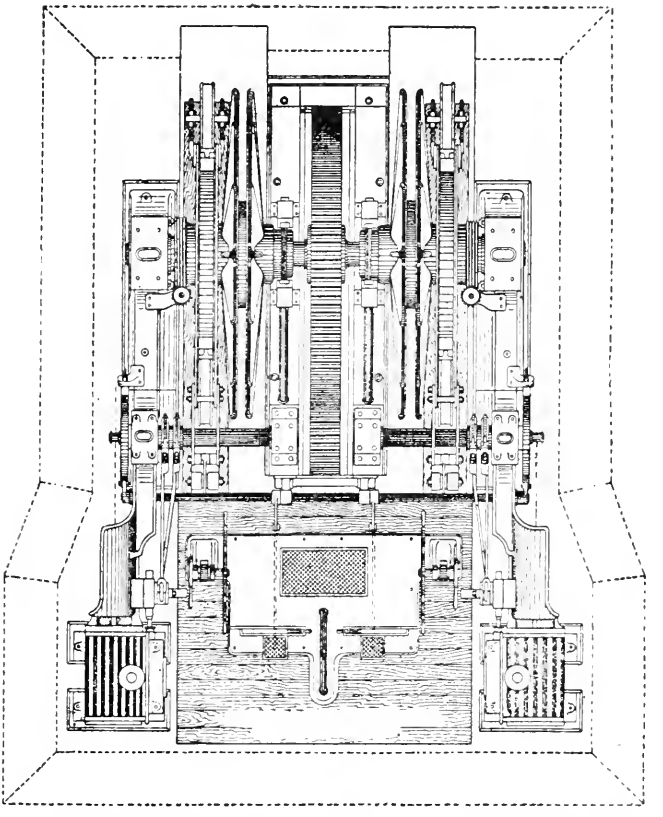


Fig. 53.—Plan of Gear Hoisting Engine, American Pattern, Flat Rope Drums.

Pit Head Gear.—The pit head gear may be constructed of wood or of steel, in which latter case it can be made extremely light for transport, and at the same time enormously strong.

When made of wood, pitchpine is usually employed, the construction being shown in figs. 54 and 57. The frame should be as high as possible, as its height represents the margin of safety left to the engine-man against overwinding. With high speed direct acting engines, the lift may be as much as 50 ft. for each stroke of the engine, but with the

geared engines generally used in metalliferous mining, the lift per stroke is correspondingly less. The height varies between 30 ft. and 70 ft., and is greater with iron pit head frames than with wood, owing to the greater strength and stability with which high structures can be made in the one case than in the other.

The uprights, two or four in number, forming the frame, and the two backstays or inclined pieces, are the main features of the framework, and must be so arranged as to best resist the vertical lifting strain and the backward pull towards the engine house. The main timbers are

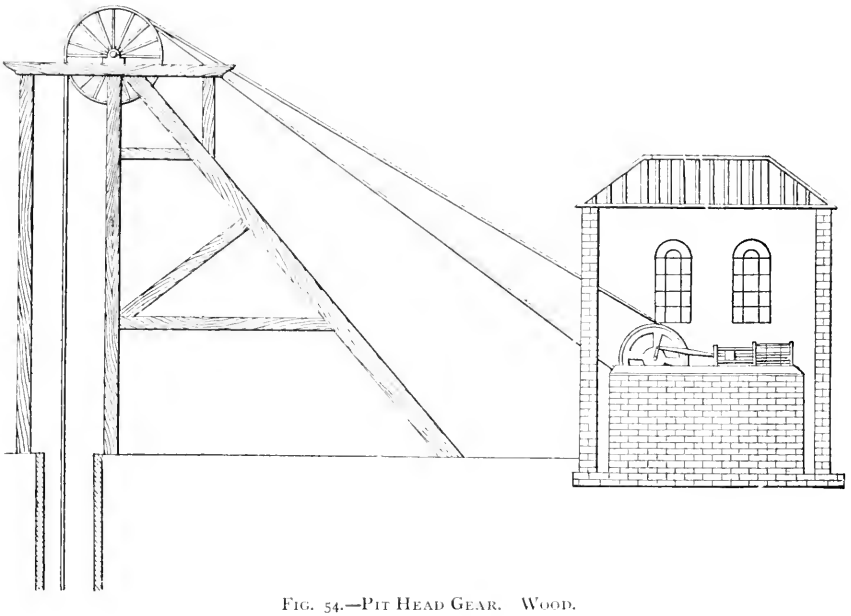


Fig. 54.—Pit Head Gear. Wood.

from 12 in. to 16 in. square, strongly jointed, and bound together over the more important joints with wrought iron straps. The double tenon joint, secured by an iron bolt passing through each tenon is the most suitable ; and careful workmanship must be exacted throughout, so that the joints may fit accurately and flush. Before being finally bound together each joint must be painted over with red-lead, and the vertical legs, as well as the backstays, should fit into a cast iron footing resting on a concrete foundation.

The angle of the backstays should be as nearly as possible that of the rope, and this latter should not make a less angle than 45° over the pulleys, in order to lessen the wear and tear of the rope. The diameter of the pulleys should be as great as possible, and varies

from 10 ft. to 20 ft. A good rule is to make them of the same diameter as the winding drum. They are now almost universally made with a cast iron boss and rim, and wrought iron spokes.

The groove is V-shaped or flat according to whether round or flat ropes are used. The pulleys are keyed on to wrought iron shafts, and are carried in strong pillow blocks, with heavy gun-metal bearings and adjustable roll plates.

Both the wooden and the iron pit heads, such as that shown in fig. 55, are provided with a ladder, platform, and handrail, so that inspections may be readily made.

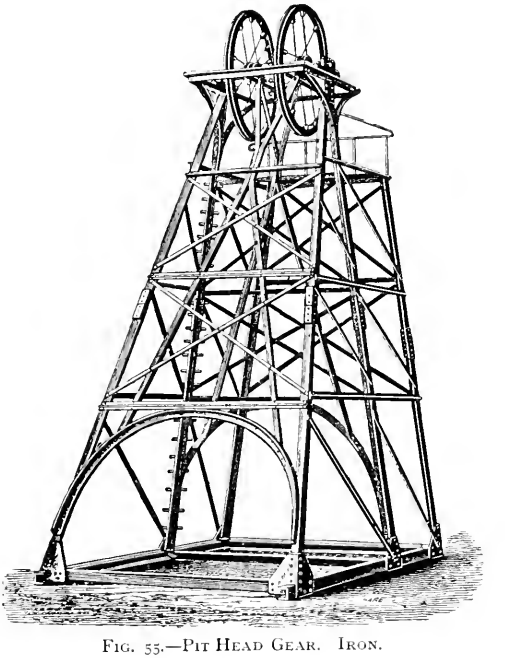


Fig. 55.—Pit Head Gear. Iron.

The Cage.—The trucks containing the mineral are run on to the platform (*a*) of the cage, shown in fig. 56, for which purpose the platform is provided with rails of the same gauge as the trucks; and the load is thus hoisted to the surface, with a minimum amount of handling. The cage itself is strongly built of Swedish iron or steel. It runs between a pair of wooden or wire rope guides, for which purpose it is provided with slides (*b b*). If wire ropes are used as guides, a clearance of from 12 in. to 18 in. must be left, so that the cages in passing each other may run no risk of collision. With rigid wooden guides this may be reduced to 9 in. The uprights on either side are provided with a slot (*c*) through which the bolts which hold the guide rods may be tightened.

The cage is fitted with cam-shaped safety catches (*d d*) which are held away from the guides whilst the weight of the cage hangs on the rope, but are released and spring against them immediately the strain is taken off the rope, either by breaking or otherwise.

The hood (*e*) is provided in order to protect the men from being injured by anything falling in the shaft, and is hinged to open towards the centre, so that it may be thrown back out of the way and admit of long timbers being carried on end.

If required, the cage may be double-decked, so as to carry two trucks, one below the other. For the comparatively light loads contained in the tram waggons of a colliery, the cages are made to carry two waggons on each deck, and so lift four at a time. The enormous quantities of coal raised per day could not otherwise be dealt with; but the weight of a truck of ore does not permit of its being handled in that fashion.

On arriving at the surface, or at one of the various levels in a mine, the cage is supported on the "keeps" (*f f*) shown in fig. 56. The cage in passing opens these, and then is dropped on the top of them, being thus brought to the exact level of the rails on the pit bank. When the cage is raised again the lever (*g*) is drawn back, and the keeps are thus held clear, while the cage passes through and down the pit.

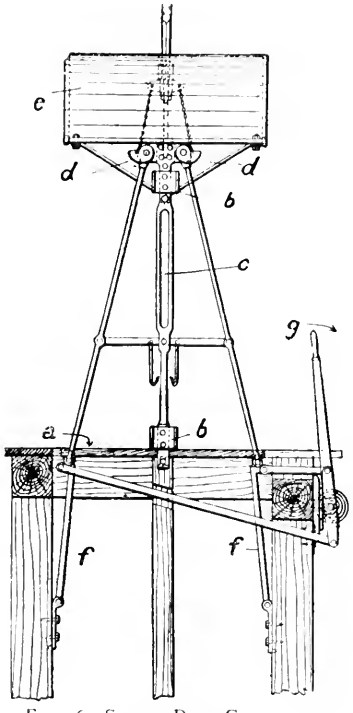


Fig. 56.—Single Deck Cage, with Landing Dogs.

The winding rope is attached to the cage by a short length of chain shackle, and is usually provided with a safety detaching hook, for the prevention of over-winding. This hook is so arranged that when it passes through a funnel-shaped cast iron cylinder fixed on the pit head, the winding rope is detached, the cage held suspended, and an accident thus avoided.

A good and complete arrangement of boilers, winding and pumping engines, and pit head gear is shown in fig. 57, which also illustrates the construction of a double pit head gear in wood. Where the quantity of water is small the pumps can be driven by the winding engine, or tanks be fitted into the cages for winding out the water.

Pit Head and Hoisting Plant for Inclined Shafts.—The hoisting plant described for vertical shafts is not adapted to those which follow the lode downwards on the line of its dip. For shafts of this description an arrangement such as that illustrated in fig. 58 is the most suitable.

The skip, with its load of minerals, runs on longitudinal wooden sleepers, the upper surface of which is covered with a slip of iron in order to resist the wear. The skip itself is of iron or sheet steel of the form illustrated in fig. 59. The tread of the leading wheels

is half the width of that of the trailing, and the rope is attached to on iron hoop hinged at the back of the skip. At the surface, or at any

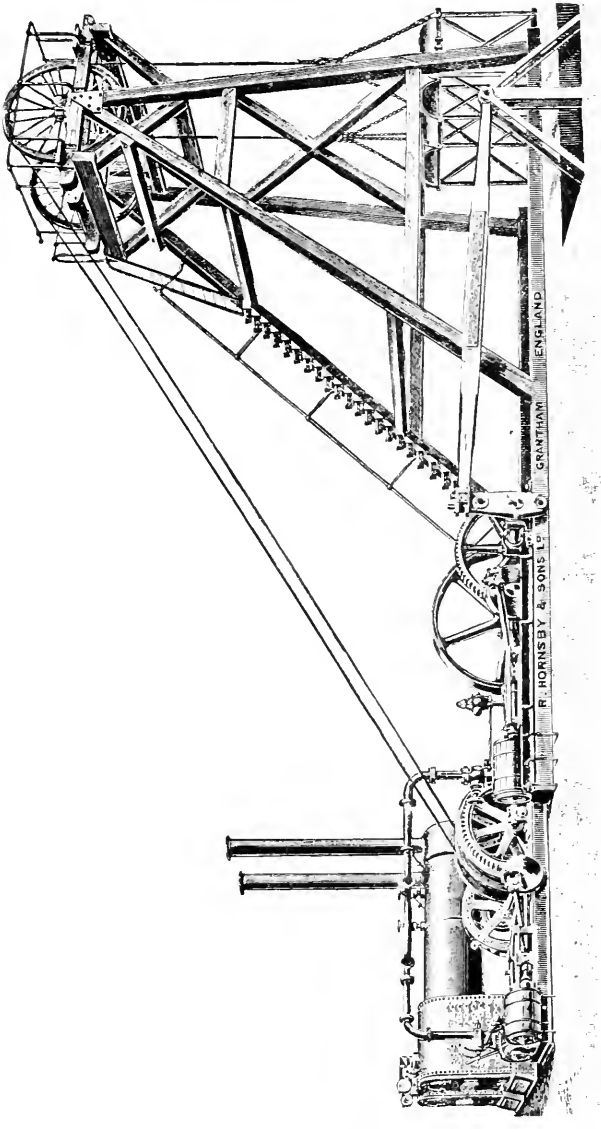


FIG. 57.—ARRANGEMENT OF WINDING GEAR AT PIT HEAD.

suitable point above it for tipping purposes, there is a break in the sleepers, which decreases them by half their width, the result of which is that the leading wheels, being narrower in the tread, follow this break

on an almost horizontal line, while the trailing wheels keep to the original sleepers. The skip is thus automatically tipped, as shown in

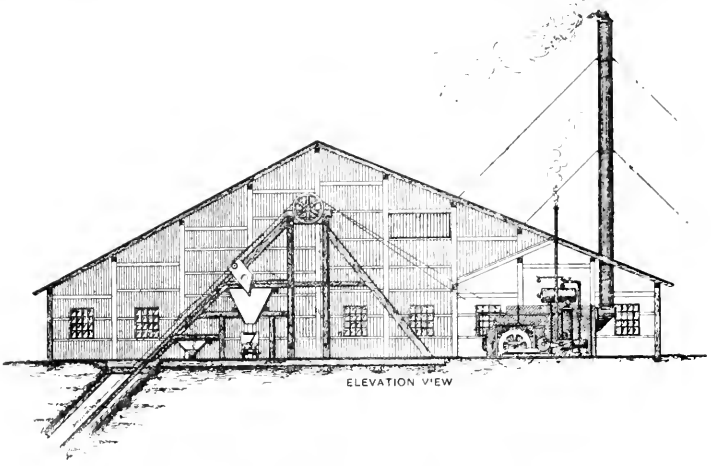


Fig. 58.—Complete Hoisting Plant for Inclined Shaft.

fig. 59; and upon the rope being slacked resumes its original position and descends empty for a new load of ore.

The winding plant may be of any desired pattern, and usually consists

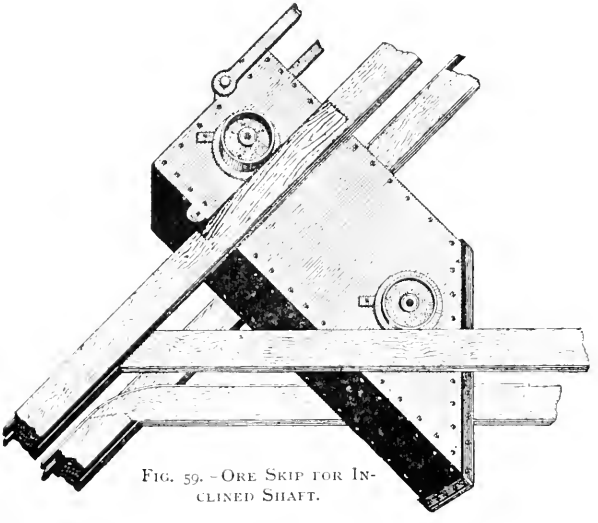


Fig. 59.—Ore Skip for Inclined Shaft.

of a double drum geared to single or double hoisting engine, which receives its steam from a pair of boilers. The pit head is constructed of wood, with overhead sheaves, over which the winding ropes work in the ordinary manner. The skip used for winding water acts on the

same principle as the others, but is provided with a valve in the bottom, through which the water may enter.

The engines shown in fig. 58 are described on page 86.

Special arrangements have to be made for loading the skips in inclined shafts at the various levels from which ore is drawn, as they cannot leave the rails of the shaft for the purpose.

In Cornwall this is carried out as shown in fig. 60.* The ore arrives from the stopes in a tram waggon along the rails of the level, the mouth of which is shown in the illustration, and is then tipped into an ore bin, where it is allowed to accumulate until the bin is full. The mouth of the bin is closed with a shutter, and below it there is a small platform on which a couple of men may stand for the purpose of loading the skip. When the ore is to be wound the skip is stopped at the level of the platform, its weight resting on an iron framework drawn across the shaft, as shown in the illustration. By this means the weight is taken off the rope and the skip held in exactly the right position. Loading is then commenced, the big lumps being thrown in by hand and the fine shovelled in until the bin is empty, when the fillers withdraw the iron framing, and the skip can then descend to a lower level and be filled with ore from another bin.

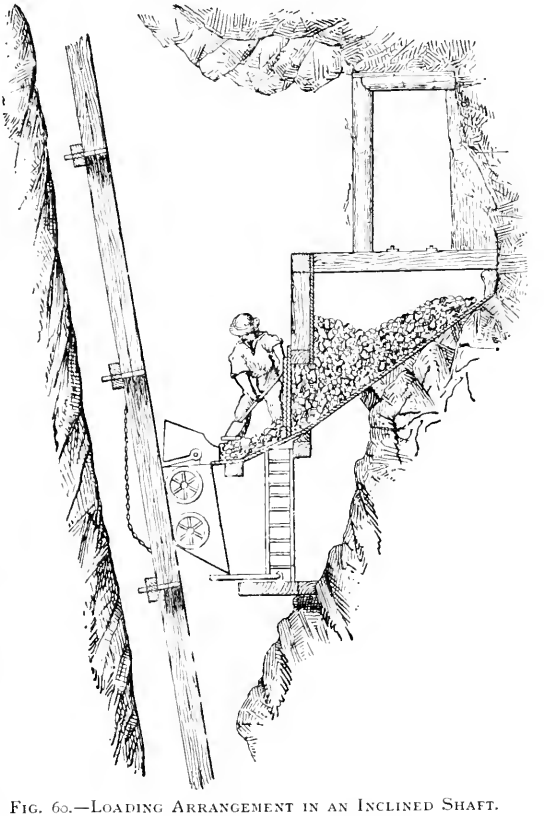


Fig. 60.—Loading Arrangement in an Inclined Shaft.

A signal wire is fitted in the shaft, as usual, so that the fillers can communicate with the engine-man. The position of the various loading platforms is marked on the indicator in the engine-room, so that the engine-man knows exactly the conditions under which he is working.

* This illustration appears in "British Mining," by Robert Hunt. London: Crosby Lockwood & Son.

CHAPTER V.

THE DRAINAGE OF MINES AND PUMPING MACHINERY.

Adits—Winding Barrels—Pumping Arrangements—Action of Pump—Plunger—Pump—Pump Rods—Balance Bobs—Details of Pumping Lift—Quantity of Water delivered at Each Stroke—Pump Pipes—History of Development of the Cornish Pumping Engine—Watts—Hornblower—Woolf—Duty of Engines—The Cornish Engine—The Cataract Governor—Cost of Cornish Engines—Husband's Safety Governor—The Geared Engine—The Direct Action Compound Pumping Engine (Surface)—Direct Acting Steam Pumps—The Worthington Pump—The Duplex Arrangement—The High Duty Attachment—Indicator Cards of Worthington Pumps—Pumping Tests—Worthington Pump at Osborne Hollow—The Riedler Pump.

The Drainage of Mines.—The best and most economical way of draining a mine is doubtless by means of an adit level, but unfortunately this is not always possible. In some cases, where a large group of mines are to be unwatered, it will pay to go to even great expense in driving long adits, as in the case of the Sutro tunnel to the Comstock lode and the Halkyn Mountain Deep Drainage scheme, Flintshire.

In most mines, however, the adit can only be driven to tap the workings at a comparatively shallow depth, and in these cases, as well as in those where no adit can be constructed owing to the conformation of the surface, some mechanical means must be contrived in order to raise the water from the bottom of the shaft up to the level of the adit or to the surface, as the case may be.

If the quantity of water is but very small it can be raised by winding in skips, barrels or bowks; but usually it is found more economical to put in a set of pumps, as with only 20 gallons a minute to be removed it would take more than six hours' winding, lifting one ton at a time and twenty tons an hour, to clear the shaft.

Where the quantity is small it is allowed to accumulate in a sump or reservoir, from which it is wound during the night or at other convenient times. For this purpose a water barrel is attached to the end of the winding rope, or a water tank slipped into the cage.

The usual form of a water tank is shown at c, in fig. 61, and may be made to hold up to 500 gallons. At the bottom is a valve, which lifts when the barrel strikes the water, and allows it to fill. When it is raised to the surface a platform is pushed over the mouth of the shaft and the

barrel lowered on to it. The spindle of the valve strikes the platform, raises the valve, and automatically empties the barrel. The water is conducted away through suitable channels.

As soon as a mine obtains considerable proportions, and when the permanent shafts are sunk, the simple method of winding out the water will no longer suffice to keep the workings dry, so that a permanent pumping plant becomes a necessity. For comparatively shallow depths it is usual to employ a bucket lift only, but for greater depths a forcing lift is used in addition, the bucket lift being placed near the bottom of the shaft. This is used to lift the water to a certain height, from which again it is forced by a plunger or forcing lift.

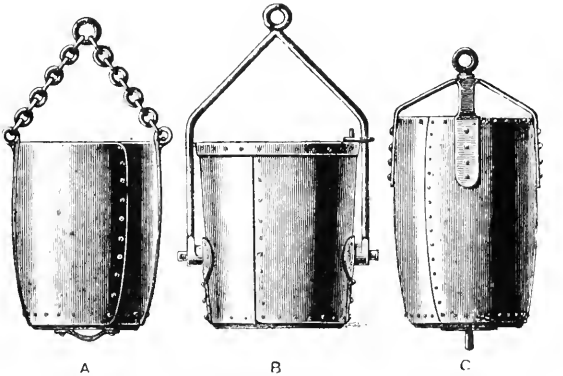
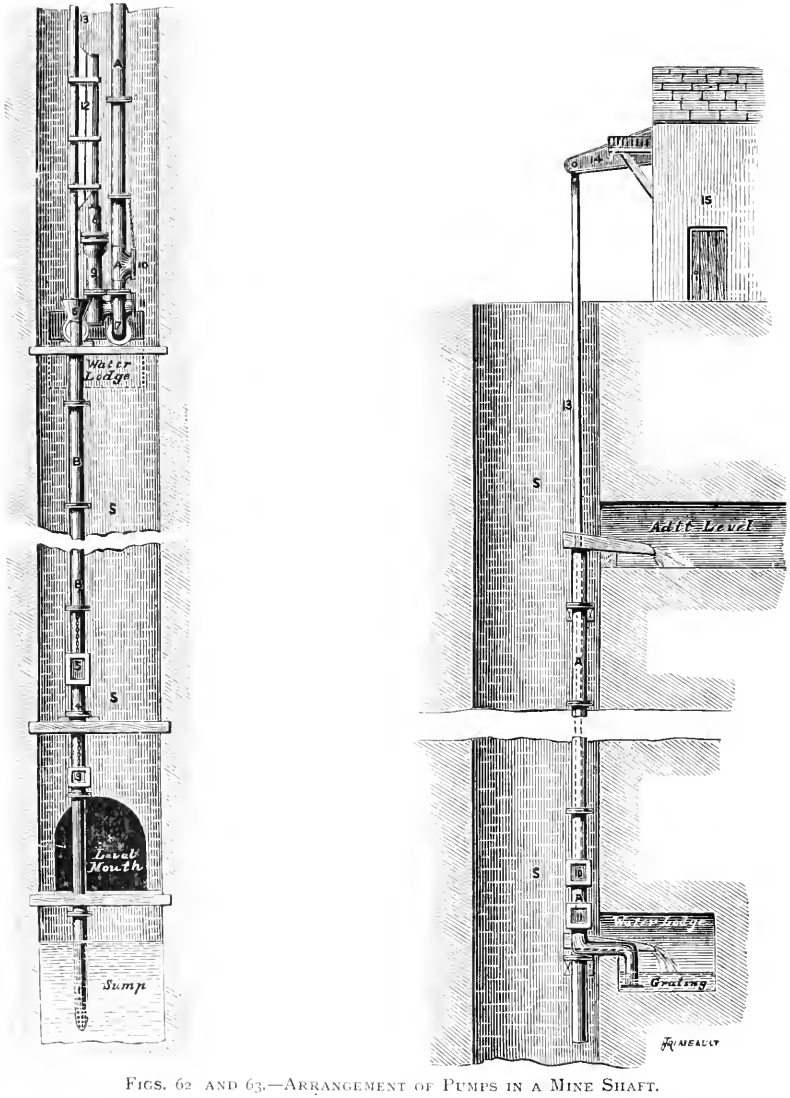


FIG. 61.—A. Kibble for Winding Ore. B. Tipping Kibble or Bowk. C. Barrel for Winding Water with Valve at Bottom.

The ordinary pumping arrangements are shown in figs. 62 and 63, in which fig. 62 represents the pumps in the shaft, and fig. 63 is a continuation of the same at right angles to fig. 62 up to the surface. For the sake of clearness the ladderways are left out, but for great depths one or more balance bobs, shown in fig. 82 must be added to take up the weight of the rods which, in deep shafts with powerful pumps, amounts to as much as 60 tons.

It will be seen that the water is first of all drawn up from the sump by the suction pipe (1) by means of the lower or bucket lift, the bucket and valves being in the working barrel (1); the amount of suction should not exceed from 20 to 24 ft.; passing the valves the water is then lifted by the bucket up to the first water lodge, a height of about 80 to 100 yds., the pump rods working inside the lift.

It must be borne in mind that the action of a pump depends upon the atmospheric pressure, which is equal to a column of water 34 ft. high at sea level. When the bucket is raised in the working barrel of a pump it forms a vacuum behind it, more or less perfect, and into this vacuum the atmospheric pressure will drive the water and cause it to follow the bucket upwards for a distance not exceeding 34 ft. But there are various losses and defects inherent to the practice of pumping, so that the full theoretical effect cannot be obtained. The bucket, therefore, should never be raised to a height exceeding say 30 ft. from the surface of the water in the pit. As a rule, the bottom of



FIGS. 62 AND 63.—ARRANGEMENT OF PUMPS IN A MINE SHAFT.

1. Wind Bore or Suction Piece. 2. Platform and Bearers across Shaft at Mouth of Level. 3. Clack or Valve Door. 4. Working Barrel. 5. Bucket Door. 6. Wooden Shoot. 7. Suction Piece or Wind Bore of Plunger or Forcing Lift. 8. Iron Plunger or Ram. 9. Plunger Case. 10, 11. Clack or Valve Doors. 12. Set-off or Junction of Bucket Rod and Plunger Pump Rod. 13. Pump Rods rising to Junction with Working Beam. 14. Main Working Beam. 15. Engine House. A. A. Plunger Lift. B.B. Bucket Lift. S. S. Shaft.

the working barrel is not more than 9 to 12 ft. above the wind bore or blast piece, and as the stroke of the bucket or plunger rarely exceeds

12 ft., the total suction is under 24 ft., so that the pump is kept at work under the most favourable conditions and the bucket should be effective for the full length of its stroke.

The plunger or forcing lift commences at the first water lodge, the lifting rods of the bucket lift being here connected to the forcing rods as shown at 12 in fig. 62.

The rods now no longer work inside the pump and so contract its area, but outside, being guided at intervals in the shaft and forcing upwards by their weight, acting through the plunger at their foot, the column of water in the pipes.

The plunger works through a stuffing box into a plunger case of bored cast iron, and at every down stroke forces a column of water equal to its own bulk through the valves into the pump pipes.

The number of lifts in a shaft depends upon its depth; as a rule, there is one for every 100 yds.

The pump rods, which play a most important part, are made of straight square balks of wood in sections of from 30 to 40 ft. long, joined together by scarfed joints and secured by wrought iron plates bolted through the timber. Sometimes these plates are placed on two sides only, but often a plate on each of the four sides.

The plungers of the pumps are fastened to the main line of pump rods by means of a set-off, as shown in fig. 62, at the several levels. In perpendicular shafts the rods work in guides in order to keep them in a straight line, and at these points they are cased with hard wood and greased in order to lessen the friction. In inclined shafts the rods run on rollers, but in other respects the arrangements are the same.

The size of the pump rods or spears depends upon the work expected from them, and roughly are the square of the diameter of the pump plunger in section. The following table will give the proportionate sizes of the rods and connections :—

TABLE OF APPROPRIATE SIZES AND PROPORTIONS OF PUMP RODS (*Carr*).

Diameter of Pumps.	Spears or Rods.	Spear Plates and Bolts.				
	Scantling Square.	Length.	Breadth.	Thickness in the Middle.	Thickness at the Ends.	Diameter of Bolts.
Inches.	Inches.	Feet.	Inches.	Inches.	Inches.	Inches.
6	3	6	$2\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{16}$	$\frac{5}{8}$
8	$3\frac{1}{2}$	$6\frac{1}{2}$	$2\frac{1}{4}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{11}{16}$
10	4	7	3	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{3}{4}$
12	$4\frac{1}{2}$	$7\frac{1}{2}$	$3\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{16}$	$\frac{13}{16}$
14	5	8	$3\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{8}$	$\frac{7}{8}$
16	$5\frac{1}{2}$	$8\frac{1}{2}$	4	$\frac{11}{16}$	$\frac{7}{16}$	$\frac{15}{16}$
18	6	9	4	$\frac{11}{16}$	$\frac{7}{16}$	$\frac{15}{16}$
20	$6\frac{1}{2}$	$9\frac{1}{2}$	$4\frac{1}{2}$	$\frac{7}{8}$	$\frac{1}{2}$	1
22	7	10	$4\frac{1}{2}$	$\frac{15}{16}$	$\frac{11}{16}$	$1\frac{1}{8}$
24	$7\frac{1}{2}$	$10\frac{1}{2}$	$4\frac{3}{4}$	1	$\frac{3}{4}$	$1\frac{1}{4}$

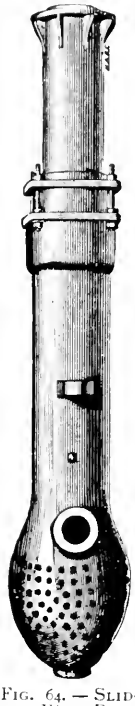


Fig. 64. — Sliding Wind Bore or Suction Pipe.

The weight of the rods is usually in excess of that required to lift the water and overcome friction, and the excess must be relieved by means of a balance bob (fig. 82) which consists of a beam of iron or timber of from 20 ft. to 30 ft. long, turning upon an iron axle, and loaded at the one end with a box filled with stones or scrap iron.

The excess weight of the rods is thus balanced, but with the single action Cornish pumping engine described on p. 105, it must be remembered that as the down stroke of the rods causes the up stroke of the engine, there must always be left a sufficient excess of weight in order to effect this. When, however, a double-acting engine is employed, such as the compound horizontal Corliss engine shown in fig. 82, where force of the steam is used equally on both sides of the piston, the more nearly the weight of the water in the rising mains corresponds to the weight of the rods the better, so that the engine may have an equal amount of work to do during both portions of the stroke, and may run with greater regularity.

Fig. 65. Working Barrel.

The various parts of a pumping lift are shown in figs. 64 to 74.

Fig. 64 is a sliding wind bore or suction pipe used in sinking in connection with a bucket lift. It is made of extra strength in order to resist the shock of the stones during blasting operations. A handhole is left, which is

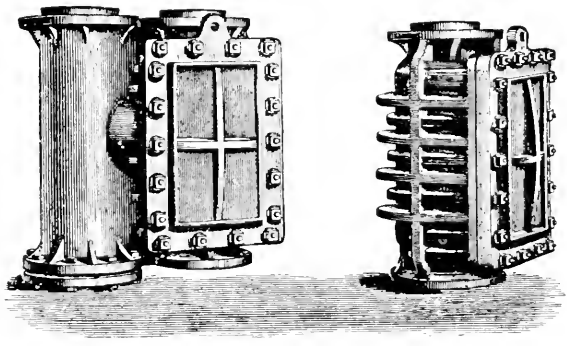


Fig. 66.—H-Piece and Door. Fig. 67.—Clack Piece and Door.

closed by a wooden plug, and is used for clearing the inside of the other holes.

Fig. 65 is the working barrel of a bucket lift, accurately bored out so that the bucket may fit perfectly. The ends are bored slightly conical, in order to facilitate the entry of the bucket. The pipes for the lift are of the same form, with the exception that they are not bored out but left rough. The flanges are turned so that the joints may be perfect.

Fig. 72.

Fig. 73.

Fig. 69.

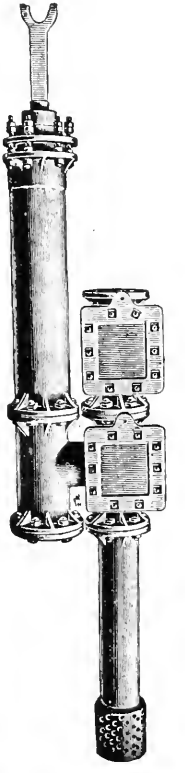


Fig. 74.—Plunger Pump with Plunger, Valves and Wind Bore.

Fig. 68.

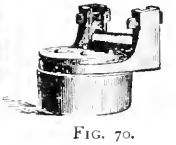


Fig. 70.

Fig. 71.

Fig. 66 is the H-piece and door for a plunger set with the clack and a portion of the plunger or pole case attached by a branch.

Fig. 67 is a clack piece and door for either a plunger or bucket lift, and is strengthened by means of numerous ribs in order to resist the shock and pressure of deep lifts.

Fig. 68 is a bucket and sword to suit a Y-rod, as shown in fig. 69, to which it is attached by means of the clasp joint. The bucket valves

are made of leather, strengthened with iron; and the bucket packing is also of leather, held in place by means of an iron hoop.

Fig. 70 is a clack or valve for a plunger or bucket lift. The valve is of leather, strengthened with iron plates. For bucket lifts, when it is required to draw the clack up inside the pipes, the form shown in fig. 71 is used.

Fig. 72 shows a set of strapping plates and brasses for connecting the wooden rods to the engine or to the tee-bob.

Fig. 73 is a pair of ordinary strapping plates for making the joints in the wooden pump rods.

Fig. 74 represents a plunger pump fitted up with the plunger, H-piece and valves, together with the wind bore.

The plunger is connected to the rods by means of a Y-piece, as shown in fig. 69, but in the illustration only the lower part of the piece is shown.

The pump lift is secured in the shaft on massive timber bearers, the rods of the plunger lift are stayed at intervals, and at those points where they pass through guides a sheathing of hard wood is provided in order to receive the wear and tear which otherwise would soon cut the rod in two. One great advantage of the Cornish pumping lift is that the engines are on the surface above the mine and are accordingly always accessible for repairs. The efficiency of the lift depends upon the state of the valves, bucket, and plunger packing; but in good working order the delivery may be ascertained from the following table which shows at a glance the quantity of water delivered by pumps of various diameters and strokes for each stroke of the engine:—

TABLE SHOWING QUANTITY OF WATER, IN IMPERIAL GALLONS, DELIVERED BY A PUMP AT EACH STROKE OF THE ENGINE.

Diameter of Pump in Inches.	LENGTH OF STROKE.					
	1 ft. 6. in.	2 ft.	2 ft. 6 in.	3 ft.	3 ft. 6 in.	4 ft.
3	0·46	0·61	0·76	0·91	1·06	1·22
4	0·82	1·09	1·36	1·63	1·90	2·17
5	1·27	1·70	2·12	2·55	2·97	3·40
6	1·84	2·44	3·05	3·67	4·28	4·89
7	2·50	3·33	4·16	4·99	5·82	6·66
8	3·26	4·35	5·43	6·52	7·61	8·70
9	4·13	5·50	6·88	8·26	9·63	11·01
10	5·10	6·80	8·50	10·20	11·90	13·60
11	6·17	8·22	10·27	12·33	14·39	16·45
12	7·34	9·79	12·23	14·68	17·13	19·58
13	8·61	11·49	14·36	17·23	20·10	22·98
14	9·99	13·32	16·65	19·98	23·31	26·65
15	11·47	15·29	19·11	22·94	26·76	30·59
16	13·05	17·40	21·76	26·11	30·46	34·81
17	14·73	19·65	24·56	29·47	34·38	39·30
18	16·52	22·02	27·53	33·04	38·54	44·05

TABLE SHOWING QUANTITY OF WATER, IN IMPERIAL GALLONS, DELIVERED BY A PUMP AT EACH STROKE OF THE ENGINE (*continued*).

Diameter of Pump in Inches.	LENGTH OF STROKE.					
	1 ft. 6 in.	2 ft.	2 ft. 6 in.	3 ft.	3 ft. 6 in.	4 ft.
19	18·40	24·54	30·67	36·81	42·94	49·08
20	20·39	27·19	33·99	40·79	47·59	54·39
21	22·48	29·98	37·47	44·97	52·46	59·96
22	24·68	32·90	41·13	49·36	57·59	65·81
23	26·97	35·96	44·95	53·94	62·93	71·93
24	29·37	39·16	48·95	58·74	68·53	78·32
25	31·87	42·49	53·11	63·73	74·35	84·98
26	34·47	45·96	57·45	68·94	80·43	91·92
27	37·17	49·56	61·95	74·34	86·73	99·13
28	39·97	53·30	66·62	79·95	93·28	106·61
29	42·88	57·18	71·47	85·77	100·06	114·36
30	45·89	61·19	76·48	91·78	107·08	122·38
31	49·00	65·33	81·66	98·00	114·33	130·67
32	52·21	69·62	87·02	104·43	121·83	139·24
33	55·53	74·04	92·55	111·06	129·57	148·08
34	58·94	78·59	98·24	117·89	137·54	157·19
35	62·46	83·28	104·10	124·93	145·75	166·57
36	66·08	88·11	110·13	132·16	154·19	176·22
	4 ft. 6 in.	5 ft.	5 ft. 6 in.	6 ft.	6 ft. 6 in.	7 ft.
3	1·37	1·52	1·68	1·83	1·97	2·13
4	2·44	2·72	2·99	3·26	3·53	3·80
5	3·82	4·25	4·67	5·10	5·52	5·95
6	5·50	6·11	6·73	7·34	7·95	8·56
7	7·49	8·32	9·16	9·99	10·81	11·65
8	9·78	10·87	11·96	13·05	14·13	15·22
9	12·38	13·76	15·14	16·52	17·89	19·27
10	15·30	17·00	18·70	20·40	22·10	23·80
11	18·50	20·55	22·62	24·67	26·72	28·78
12	22·02	24·47	26·92	29·37	31·81	34·26
13	25·85	28·72	31·59	34·47	37·33	40·21
14	29·97	33·30	36·64	39·97	43·29	46·63
15	34·41	38·23	42·06	45·89	49·70	53·53
16	39·16	43·51	47·86	52·22	56·57	60·92
17	44·21	49·12	54·03	58·95	63·85	68·77
18	49·55	55·06	60·57	66·08	71·58	77·09
19	55·21	61·35	67·48	73·62	79·75	85·89
20	61·18	67·98	74·78	81·58	88·38	95·18
21	67·45	74·95	82·44	89·94	97·43	104·93
22	74·03	82·26	90·49	98·72	106·95	115·17
23	80·91	89·90	98·90	107·89	116·87	125·87
24	88·11	97·90	107·69	117·48	127·27	137·06
25	95·60	106·22	116·85	127·47	138·08	148·71
26	103·41	114·90	126·39	137·88	149·37	160·86
27	111·51	123·90	136·30	148·69	161·07	173·47
28	119·93	133·25	146·58	159·91	173·23	186·56
29	128·65	142·95	157·24	171·54	185·83	200·13
30	137·67	152·97	168·27	183·57	198·86	214·16
31	147·00	163·33	179·67	196 01	212·33	228·67
32	156·64	174·05	191·45	208·86	226·26	243·67
33	166·59	185·10	203·61	222·12	240·60	259·14
34	176·83	196·48	216·13	235·79	255·43	275·08
35	187·39	208·21	229·03	249·86	270·68	291·50
36	198·24	220·27	242·30	264·33	286·35	308·38

TABLE SHOWING QUANTITY OF WATER, IN IMPERIAL GALLONS, DELIVERED BY A PUMP AT EACH STROKE OF THE ENGINE (*continued*).

Diameter of Pump in Inches.	LENGTH OF STROKE.					
	7 ft. 6 in.	8 ft.	8 ft. 6 in.	9 ft.	9 ft. 6 in.	10 ft.
3	2·28	2·45	2·59	2·74	2·89	3·06
4	4·07	4·35	4·61	4·89	5·16	5·44
5	6·37	6·80	7·22	7·65	8·07	8·50
6	9·17	9·79	10·39	11·00	11·61	12·23
7	12·48	13·32	14·15	14·98	15·81	16·65
8	16·31	17·40	18·48	19·57	20·65	21·75
9	20·64	22·03	23·39	24·77	26·65	27·53
10	25·50	27·20	28·90	30·60	32·30	34·00
11	30·84	32·90	34·95	37·00	39·05	41·12
12	36·71	39·16	41·60	44·05	46·49	48·95
13	43·08	45·96	48·83	51·70	54·57	57·45
14	49·96	53·30	56·62	59·95	63·27	66·62
15	57·35	61·19	65·00	68·82	72·64	76·48
16	65·27	69·62	73·97	78·32	82·67	87·02
17	73·68	78·60	83·51	88·42	93·33	98·25
18	82·59	88·11	93·60	99·11	104·61	110·13
19	92·02	98·17	104·29	110·43	116·56	122·71
20	101·98	108·78	115·57	122·37	129·16	135·97
21	112·42	119·93	127·41	134·91	142·40	149·91
22	123·40	131·63	139·84	148·07	156·29	164·53
23	134·86	143·86	152·84	161·83	170·81	179·82
24	146·85	156·65	166·43	176·22	186·01	195·81
25	159·33	169·97	180·58	191·22	201·82	212·46
26	172·35	183·85	195·33	206·82	218·31	229·81
27	185·86	198·26	210·64	223·03	235·41	247·82
28	199·89	213·22	226·54	239·86	253·18	266·52
29	214·42	228·72	243·01	257·31	271·16	285·90
30	229·46	244·76	260·05	275·35	290·64	305·95
31	245·00	261·35	277·67	294·00	310·33	326·68
32	261·07	278·48	295·88	313·29	330·69	348·10
33	277·65	296·16	314·67	333·18	351·69	370·20
34	294·73	314·39	334·02	353·67	373·31	392·98
35	312·32	333·15	353·96	374·78	395·60	416·43
36	330·41	352·44	374·46	396·49	418·51	440·55

The motive power which actuates the pump rods may be either water or steam or in modern times electricity.

Pump Pipes.—The material used for pump pipes varies to suit the conditions, including kind of water, pressure, climate, facilities of transportation and cost. Cast iron was formerly exclusively used for large pipes subjected to pressure underground, but it is now rarely employed in American mines for this purpose. While cast iron is less subject to corrosion than either wrought iron or steel, the pipes made of it are very heavy, and the sections therefore more difficult to handle.

Wrought iron or steel pipe, on account of less cost, its greater security under water hammer, and the facility with which sections of any length can be cut and fitted to place at the mine, has led to its almost universal use.

It is a general fault of pipe manufacturers to recommend pipe of insufficient thickness. This, of course, is due to the strong competition, and the fact that mining men, as a rule, do not themselves calculate the strain on the metal in the pipe. The bursting of the column pipe in a mine might not only cause great damage to machinery and surroundings, but also loss of life.

In a great many instances, the mine water is very acid, which causes a corrosive action on iron pipes and their rapid destruction. When this is the case it is necessary to resort to other materials. Many different mixtures of bronzes have been used, but even these have often been unable to withstand the severe action of the acid water in many mines. Bronze pipe, of course, is very expensive. At the Barranca Mine, in Mexico, drawn copper tubes were put in at a great cost. In many instances, where no commercial metal could be found to withstand the action of the acid water, and where the pressure is not great, wooden pipes are used. For higher pressures, iron pipes lined with wood soaked in asphalt have given good results. The wood used in this case is generally redwood or the like. Iron and steel lap-welded tubes up to 30 in. diameter can be obtained. Welded pipes are either lap-welded or butt-welded. The latter should be used for smaller sizes only and for moderate pressure, as they are liable to split open at the weld. Lap-welded tubes or hot riveted pipes of boiler plate are the only wrought iron pipes suitable for pump columns in shafts, and for all purposes where heavy pressures are used and water hammer liable to occur.

Welded pipes may generally be obtained in lengths of 20 ft. For very high pressure special welded tubing is made, with welded steel flanges, and in lengths of 40 ft. This is, of course, to do away with as many joints as possible. For facility in handling, the sections composing mine column pipes are usually not over 16 ft. in length. For long pipe lines of comparatively large size, riveted steel pipe is commonly used, made up of plate steel with single, double, or treble riveted longitudinal seams, and single or double riveted transverse seams.

Steam Pumping Machinery.—We will now proceed to investigate briefly the introduction of the steam engine, and its development as applied to the pumping of water from mines. It is hardly perhaps necessary to notice the use of water-wheels for this purpose, as their application consists only of a crank on the waterwheel shaft connected by means of iron rods running on pullies with the tee-bob at the top of the shaft. The line of rods on the surface is often of great length, with all sorts of contrivances for getting around corners. The loss of power in friction is enormous.

The usual speed of a waterwheel applied to this purpose is from

4 to 6 revolutions per minute; but its motion is irregular as it lifts the column of water on one half stroke and is pulled over by the weight of the falling rods on the other half. The remains of these wheels dot the hillsides of Cornwall and Wales, but more especially in the latter country owing to the abundance of water, though the great wheel at the Laxey Mine in the Isle of Man is the most notable example of work of this description.

Thomas Newcomen and John Cawley, of Dartmouth, are supposed to have been the makers of the first steam or atmospheric engine that successfully worked a pump for the drainage of mines. They erected one of their engines at Wolverhampton in 1712, which is reported to have worked successfully. In the year 1737 we find an engine of Newcomen's construction working a succession of 7-in. lifts, having a stroke of 6 ft., at the rate of 15 strokes per minute; each lift was but 24 ft. in length, so 11 of them were required to raise the water from the shaft, which was 267 ft. deep.

The Newcomen engine was greatly improved by Smeaton, who erected one of his improved engines in the Chasewater Mine, near Truro, Cornwall, in 1775. This engine had a cylinder 72 in. diameter, with 9 ft. stroke, and it developed about 76 horse-power. It is interesting to note some of the dimensions of Smeaton's engine. The cylinder was $10\frac{1}{2}$ ft. long, and weighed 4 tons 16 cwt.; the piston was in the form of a flat circular disk, 66 in. in diameter by $1\frac{1}{2}$ in. thick, the edge of the disk being raised to form a vertical rim 5 in. high; boards were bolted on beneath the iron disk to form the actual steam-tight packing. This engine operated 3 columns of pumps, $16\frac{3}{4}$ in. diameter and 34 yds. in length, a total lift of 102 yds. The water load was estimated at 14 tons, the load on the piston being about $7\frac{3}{4}$ lb. per square inch.

In 1769 Watts had completed and patented his great discovery of a separate condenser, which was destined to revolutionise the steam engine. The Chasewater engine, though the most powerful machine in existence when erected on that mine, was also the last effort of a system then passing away—the final effort on the part of the atmospheric engine. The Chasewater engine was altered and remodelled by Watt a few years later. These alterations brought up the duty of the engine to about 20 million foot-pounds, and created, as it were, a prototype of the Cornish pumping engine, which was so rapidly developed under the guidance of Hornblower, Woolf, and Trevithick, the greatest of Cornish engineers.

In 1781 Hornblower constructed and patented a compound engine having two cylinders of different sizes, steam being first admitted into the small cylinder, then, passing over into the large cylinder, did work in each. The compound engine was revived by Woolf in 1804. No doubt Hornblower and Woolf saw clearly the advantage to be gained in expanding the steam in two cylinders instead of in one, as the sum of the forces exerted by the two pistons in the compound engine varies less than

the force exerted by the piston of the single-cylinder engine for the same amount of expansion. It is doubtful, however, if they understood the more important merit of the compound system, which lies in the fact that by dividing the whole range of expansion into two parts, the cylinders were kept at a more uniform temperature relative to the expanding steam, thus limiting the waste which results from the heating and cooling of the metal by its alternate contact with hot and cooler steam. The compound expansion is perhaps the only great improvement in the use of steam since the days of Watt; and, indeed, it is but carrying out one of the laws laid down by Watt himself, "that the cylinder should be kept as hot as the steam that enters it."

Woolf introduced his compound engine extensively about the year 1814 as a pumping engine in the Cornish mines, but on account of its complicated mechanism, and extra first cost, it did not successfully compete with the high-pressure single-cylinder engine of Trevithick, which had the advantage of simplicity of construction—a very important point in those early days of mechanical engineering; therefore Woolf's engine fell into comparative disuse, and the single-cylinder type took a form which, under the name of the Cornish pumping engine, has long been famous for its economy of fuel.

Woolf was the first who succeeded in making a wrought iron boiler tight for high-pressure steam. This was accomplished in 1817, and gave a considerable impetus to the expansive working of steam in the engine. Woolf's compound engine at Wheal Abrahams in 1815 did 52 million foot-pounds. His single-cylinder engine at Consols in 1827 is reported to have exceeded 64 millions. Thus we see Woolf found the Cornish engine with an average duty of 20 millions, and left it with over 60 millions.

The celebrated Fowey Consols engine, reported at 125 million duty in 1835 (say $1\frac{3}{4}$ lb. coal per horse-power per hour) is still quoted as almost unapproachable. This engine had an 80-in. cylinder, $10\frac{1}{2}$-ft. stroke, and could only develop 62 horse-power when accomplishing its remarkable duty.

The Cornish Pumping Engine.—The following description of the modern form of the Cornish pumping engine is chiefly taken from André's "Treatise on Coal Mining."* The cylinder (F), fig 75, is 70 in. in diameter, with a 10-ft. piston stroke. It is provided with a cast iron steam jacket, connected with the boilers by the pipe (H), fig. 75. The boilers are situated below the pipe (H) so that the water of condensation returns by it. Where the boilers, from unavoidable circumstances, are above the cylinder, the supply pipe to the steam jacket cannot serve as a return condensed water pipe, and provision must

* London: E. & F. N. Spon.

be made for freeing the jacket from condensed water by means of a steam trap. The steam jacket is encased in wood; the annular space between the two is filled with some non-conducting medium, such as sawdust, and the whole is enclosed in brickwork, either in contact

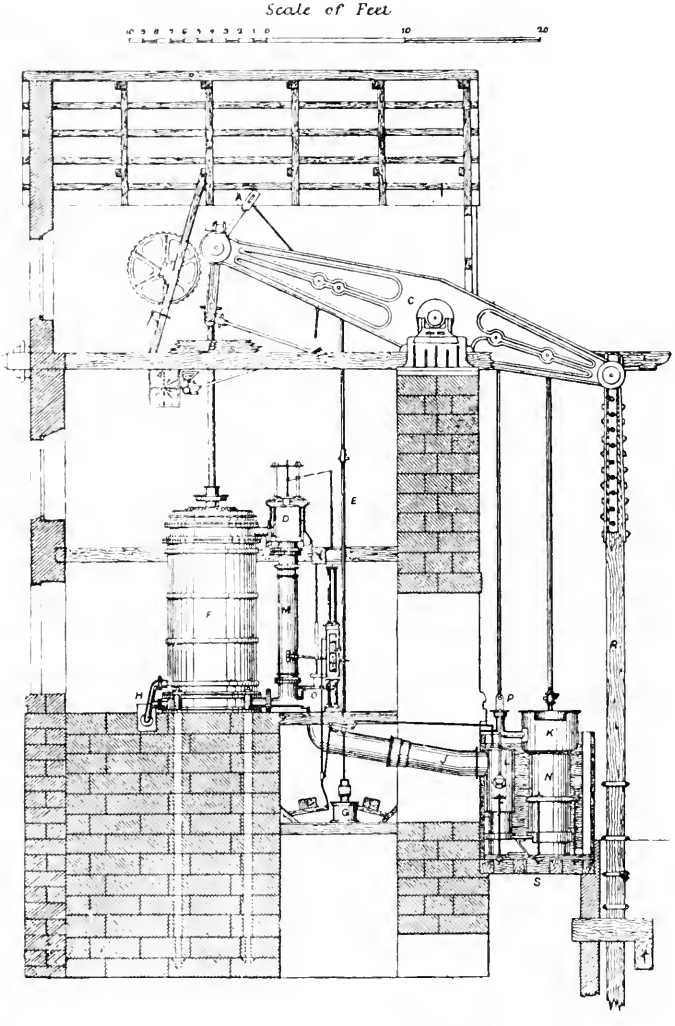


Fig. 75.—The Cornish Pumping Engine.

with the casing, or separated from it by a few inches, and is plastered on the outside, the plaster being covered with wood panelling. The cylinder cover is fitted with a false lid or cap, which encloses a thick layer of sawdust, and is thus protected from the cooling influence of

the air. The space under the cylinder bottom is protected from the same influence by steam filling it from a branch of the pipe (H). C is the main beam, cast in two plates, which are bolted together with distance blocks between them to keep them truly parallel.

A catchpiece (A) is fixed to the upper part of the beam by means of brackets. On the piston reaching the bottom of its stroke, the catchpiece touches the blocks (B) fixed on the spring beams, arresting the piston, and thus preventing injury to the cylinder by the engine making too long an indoor stroke. E is a plug or tappet-rod for working the valves and cataract; and D the top nozzle shown in fig. 76.

The nozzle contains three valves (G). Fig. 76 is the governor, or

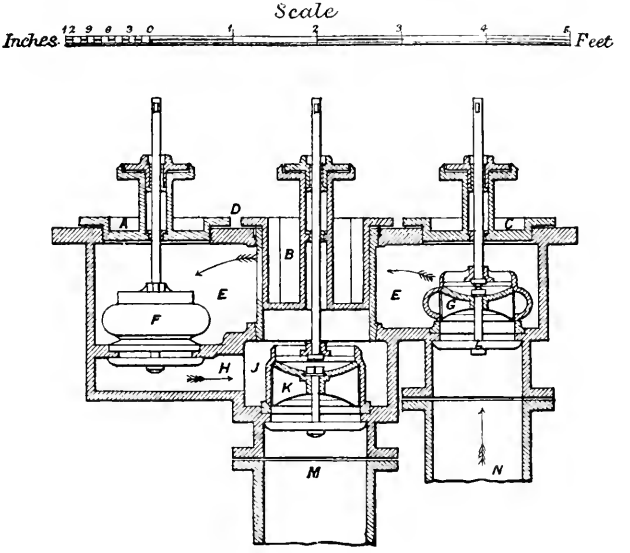


Fig. 76.—Enlarged View of the Governor Valve.

regulating valve, for regulating the admission of steam into the chamber (E E) of the nozzle, whence it afterwards passes through the steam valve (F) into the cylinder. The governor valve is not moved by the engine during its working, but is regulated occasionally by hand. In proportion to the raising of the governor valve more or less, the steam is less or more wire drawn or reduced in pressure in its passage from the steam pipe into the cylinder. By this means, although the boiler pressure may vary, the mean effective pressure in the cylinder will be kept more constant.

The motion of the governor valve is under the control of the engineman, and a handle is placed within his reach, which is connected by a rod and a lever with the valve spindle. F (fig. 76) is the steam valve,

which admits steam into the cylinder. The chamber (E E) is not separated by the cover (B) as may be thought from the drawing; but an uninterrupted passage is afforded for the steam, as shown by the arrows.

On the steam valve (F) being lifted (if the governor valve is also open), the steam is free to pass through it from the chamber (E E) to the passage (H) and thence by the steam port (J) into the upper part of the cylinder. K is the equilibrium valve, and is situated in the middle of the nozzle. On being lifted, the steam above the piston is free to find its way along the equilibrium pipe (M), figs. 75, 76, 77, and into the lower portion of the cylinder under the piston. At the

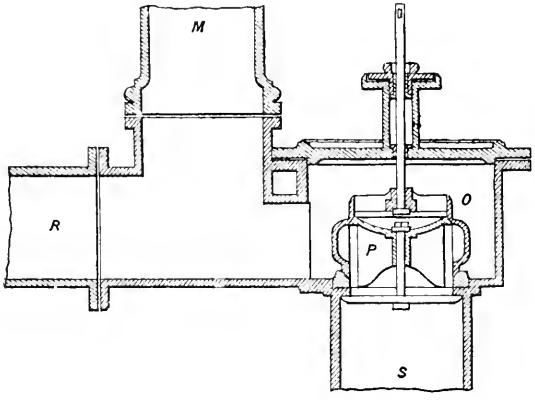


FIG. 77.—ENLARGED VIEW OF THE EQUILIBRIUM VALVE.

moment the pressure of the steam above and below became equal, the rods (R)—on account of their weight—hung at the other end of the beam, descend, and the piston is drawn upwards, the steam above acting as a cushion in its ascent.

The upper nozzle (D) has an external casing of thin iron, a space being between it and the nozzle, which is filled up with sawdust, or some other non-conducting material, to retain the heat.

A reference to fig. 76 shows that the three covers (C, A, B) which are bolted to the nozzle over the governor, steam, and equilibrium valves respectfully, are of such a size as to allow of the valves being examined or repaired in removing the covers. O is the bottom nozzle (figs. 75, 77), and shown in section in fig. 77; on it is placed the exhaust valve (P) for opening or closing the communication between the lower part of the cylinder and the condenser. Above the valve the nozzle chamber (O) is in communication with the cylinder by the lower part, and under the valve the bottom of the nozzle communicates with the eduction pipe (J on fig. 75, S on fig. 77). When the exhaust

valve is raised, the steam in the lower part of the cylinder is exhausted into the condenser (L). That the action of the Cornish valve may be rendered plainer, an enlarged section of one is given in fig. 78.

The valve is designed to give a large extent of opening for the passage of steam with little traverse, a small amount of power being necessary to work it. E is the fixed seat, made of cast iron or brass, which forms part of, or is secured to, the valve chamber. C is a bell-shaped valve piece, also of brass, actuated by a rod (B). The valve is in contact with its seat at two places (D and H) which are formed into accurate conical surfaces; the one (D) being internal, the other (H) external. When the valve is closed these surfaces accurately fit similar ones on the seat, and when lifted, as shown in fig. 78, two annular openings are formed at the same time, thus giving a double passage to the steam through the valve.

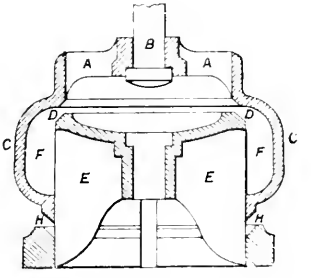


FIG. 78.—VERTICAL SECTION OF THE EQUILIBRIUM VALVE.

The spindle (B) of the valve (C) is fixed to a centre eye, cast in one with the valve piece, and connected to it by four arms, A A being two, the others being at right angles to them. The seat is also formed similarly,

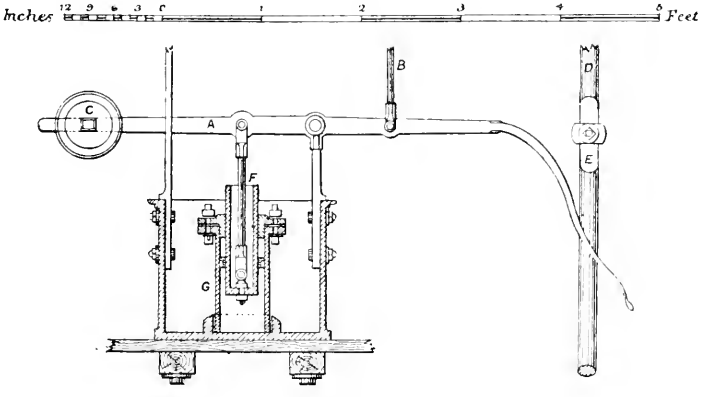


FIG. 79.—THE CATARACT GOVERNOR (SIDE VIEW).

with four arms, having an annular ring at the base, the top edge of which is bevelled and ground to fit the lower edge of the valve (C) and, when lifted, forms the opening, as shown at H. Referring again to fig. 75, it will be observed that the piston rod is connected with the end of the beam by a parallel motion, which assures the ascent and descent of the

piston rod in a vertical position, whilst the end of the beam moves through the arc of a circle.

A very striking feature of the Cornish engine is the cataract governor (G), fig. 75, shown also in section in figs. 79 and 80.

This and the parallel motion were the inventions of Watt. It consists of a pump placed in a circular tank of water below the level of the cylinder. G is a barrel, and F the plunger, working in it as an ordinary small forcing pump. The water reaches the barrel through the inlet valve (H) which opens freely upwards; but the passage for the outlet is contracted as desired by a movable plug (L). The plunger is connected by a joint to the lever (A). This lever is loaded with a heavy weight (C) and on the same side of the fulcrum as the plunger, and the lever projects on the other side of the fulcrum, terminating in the handle shown on the drawing.

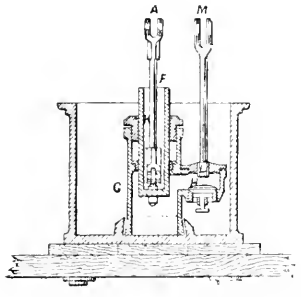


FIG. 80.—THE CATARACT GOVERNOR (END VIEW).

When the tappet or plug rod (D) which is worked off the main beam—has descended nearly to the end of its stroke, a projecting block on the lower part of it E called a tappet, strikes the end of the lever (A) and, in consequence, the plunger (F) is raised, the water flowing freely through the valve (H) and following the plunger in its ascent. After the completion of the down stroke the piston of the engine begins to ascend (due to the opening of the equilibrium valve by the tappet rod), the tappet rod also ascends and leaves the lever (A) and the heavy weight (C) which is raised at the same time as the plunger, becomes the motive power in driving the water from the pump by forcing down the plunger. The inlet valve (H) having closed before the descent of the plunger, the only passage for the water is by the aperture left round the regulating plug (L). It will be seen, therefore, that the time occupied by the pump plunger in its descent depends upon the size of this aperture, which the attendant regulates by means of the plug fitting it.

Near the fulcrum of the lever (A) but on the tappet rod side of it, a rod (B) is jointed to the lever, and ascends vertically from it. In its ascent this rod opens first the exhaust, and shortly afterwards the steam valve, thus causing the engine to commence the next down stroke. The rod (B) acts upon a catch that releases weights, which, by their fall, open the valves, causing a suddenness of action, for which considerable advantage is claimed, especially as regards the admission of steam into the cylinder by the steam valve.

The interval of time between any two consecutive strokes must therefore depend upon the time occupied in the descent of the cataract

plunger, and upon the amount of the opening given to the regulating plug (L). By means of a micrometer screw and handle connected with L, by a rod, and the lever (M) the plug can be regulated to any degree of opening required. The steam valve can thus be opened any desired number of times per minute, and the number of strokes in that interval of time thereby regulated.

J (fig. 75) is the eduction pipe, connecting the condenser (L) with the bottom of the exhaust valve nozzle (O). The size of the air-pump (N) is approximately half that of the steam cylinder, being 2 ft. 9 in. in diameter, with a 5-ft. stroke. It is fitted with a foot valve. P is an ordinary plunger-fed pump. The condenser (L) is fitted with an injection cock and valve for regulating the cold water supply to it. The pump rods (R) are frequently attached to the main engine beam, as shown on the drawing, without the intervention of a parallel motion, and with only side guides in the shaft. The consequence is that near the surface the rods deviate considerably from the vertical line in their ascent and descent; but this deviation is less at lower portions of the rods. It is a much better plan for the pump rods to be attached to the main beam by a parallel motion, so as to ensure the rods maintaining a vertical position. This may be done by a gudgeon on the top of the rods carrying two side-blocks working in cast iron guides for a sufficient length, to take the stroke of the engine. The gudgeon may be attached to the beam by two iron radius rods, the space between them being filled with pitchpine. Husband's patent gearing may be applied to the engine. In the event of breakage this gearing is intended to open the equilibrium valve and stop the engine.

The steam in the Cornish pumping engine is admitted at high pressure, and may be worked expansively, the steam being cut off at some point of the stroke, which may be from one-third to one-sixth. In consequence, however, great shocks to the engine, and especially the pit-work, when a high rate of expansion, with its accompanying high velocity during the strokes, is attempted, which shocks lead to breakage and stoppage of the pumps, it is not found advantageous to work at any but a very moderate rate of expansion, and thus economy of steam is sacrificed for safety of working. The Cornish engine being single acting, it necessarily requires a larger cylinder for a given amount of work, than a double acting engine. As regards fuel consumed, it is economically worked, from 3 lb. to 6 lb. of coal being used per hour per indicated horse-power.

The Cornish pumping engine is a wonderfully elaborate and complicated specimen of ingenuity and skill, and its cost is about £8 per horse-power. A 90-in., or 500 horse-power, therefore costs about £4000; then the three-storied engine-house and pillars for such an engine, would require about 500 cubic yds. of masonry, the price of which varies in

different localities, according to the character and price of materials, such as stone, bricks, lime, etc. In Cornwall, where suitable stone abounds, it seldom exceeds 6*s.* 6*d.* per yard. Again, the steam case must be covered with some non-conducting material, or else, having a greater surface area than the steam cylinder, it becomes a larger condenser.

Another objection to the Cornish engine is the large number of parts to maintain in an efficient state of repair and cleanliness. It has four double-beat valves with their sets of bright nozzle gear, consisting of pillars, levers, and guides, quadrants and catches on the ground floor, tappet rod carrying its adjustable blocks to work the four levers of double-beat valves and cataract governor in the basement; air-pump and condenser, with foot and delivery valves, injection cock, and valve and lever attachments; also a large cast iron beam, which, for a 90-in. engine, weighs 50 tons, and the parallel motion with its many joints, all requiring a considerable amount of attention and care.

The *duty* of a Cornish pumping engine is the quality for which it is most renowned, and is the amount of work done in relation to the amount of fuel consumed.

The method adopted in Cornwall has been to find out what weight of water has been lifted one foot high by the consumption of one bushel = 94 lb. of coal. Of late years the bushel has been exchanged for the hundredweight of 112 lb. In America the standard is 100 lb. of coal.

This found out, the ascertaining of the weight of water lifted out of a mine of a given depth is simple. Thus, if an engine by the consumption of 112 lb. of coal lifts 60,000,000 lb. of water 1 ft. high, the amount raised out of a shaft of 100 fathoms = 600 ft. deep, would be 100,000 lb. This being the result of dividing the amount raised 1 ft. by the depth of the pit.

The engines at present working on the Cornish mines are all heavily loaded, pumping from great depths, in crooked, inclined shafts, entailing very considerable friction on the rods, and a late steam cut-off, which means less expansion in the cylinder, and a low duty. From the best information obtainable, it would appear that the average duty of these engines is not at present in excess of 60 millions.

The principle on which the Cornish pumping engine was designed, and which has just been described, met fully the conditions necessary for the economic drainage of the mines, and consequently no engine has heretofore held so high or meritorious a position.

These engines are a marvel of skill, and a lasting tribute to the brilliant engineers who designed them, as well as to the workmen who, in those early days of mechanical engineering, were able to manufacture such ponderous machinery.

This engine, however, has had its days, and while it may not yet have

outlived its usefulness, yet there are few, if any, mines at which the competent mining engineer would now advise the erection of a Cornish pumping engine. We live in a progressive age, in which no machine, however excellent in its design, or however perfect in its motion, can remain without improvement for well nigh fifty years.

There are a large number of these engines still at work at home and abroad, and although no new ones of this type will probably be ever

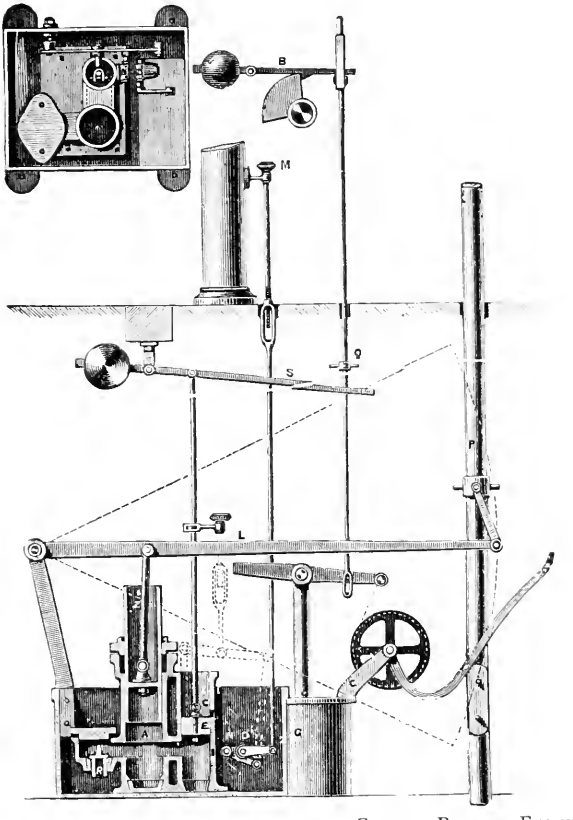


FIG. 81.—HUSBAND'S SAFETY GOVERNOR FOR CORNISH PUMPING ENGINES.

erected again, yet the old engines will remain for another century or more as triumphs of mechanical skill. It is for this reason that I have given such a full description of them, for although the engineer of the modern school will possibly never be called to erect one, it is highly probable that he may have to keep one at work.

Husband's Safety Governor for Cornish Pumping Engines.—In the pumping engines employed in mines the breaking of the main rods is

an accident to be dreaded, and is likely to be followed by serious damages to the machinery. The greatest strain is on the rods during their up stroke, when they have their own weight to support, and also that of the column of water in the bucket lift. This corresponds to the down stroke of the engine piston, which is then taking steam. On the rods breaking, the piston is suddenly relieved of its load, and the spring beams must suffer if the engine-man is not at his post. What the driver would do to prevent such a result, would be to throw up the equilibrium catch immediately he finds that the speed of the down stroke is faster than ordinary; but to do this would necessitate his being constantly at the handles, and even then he could hardly throw up the catch in time. The object of the patent governor is to act simultaneously with the engine, and stop any tendency to race, before it ends in a disaster.

The action is as follows: The plunger (Z), in fig. 81, makes its up stroke with that of the engine, and draws its water through the valve (R) forming part of the ordinary cataract system described on page 110. The water so pumped is discharged into the same cistern, through the regulating cock (D) which is adjusted by means of a rod (M) from the engine floor. If the engine increases its speed above the normal rate of working, from any cause whatever, the water is throttled in its discharge through the cock (D) and a pressure is thus imposed upon the piston (E) tending to raise it; as the piston (E) rises, the lever (S) comes in contact with the catch (Q) and thereby lifts the equilibrium catch (B) thus introducing the steam to both sides of the piston. To increase its effectiveness, an additional cock (N) is provided, which closes as the piston (E) rises, thus increasing the force of the piston. The cost of one of these appliances is small in comparison with that which would be caused by the breakage of the rods.

The Geared Engine.—The pumping lift may be worked by many different kinds of engine, according to the quantity of water, the depth of the shaft, and the value of fuel. For small quantities of water it is usual to put a crank on the end of the shaft of the winding drum, as shown in the illustration of a winding plant (fig. 45 to 48). The pump may then work intermittently at the same time as the winding, or the water may be allowed to accumulate in a large sump, from which it is pumped out at intervals, the winning drums being then thrown out of gear.

When the quantity of water is too large to admit of this simple arrangement a separate engine must be laid down, and this may either drive the pumps through gearing or direct, as described on page 115.

Where gearing is employed, the power from the engine is transmitted through a pinion on the engine shaft to a large spurwheel, and on the shaft of this latter a crank is keyed from which the long connecting rod drives the surface bob, which in turn works the pumps.

The whole arrangement may be seen by reference to fig. 57, which shows a winding and pumping plant complete, together with the timber, pit head, and cages.

When a large permanent pumping plant is required, the engine, instead of being an ordinary single cylinder high pressure engine, as

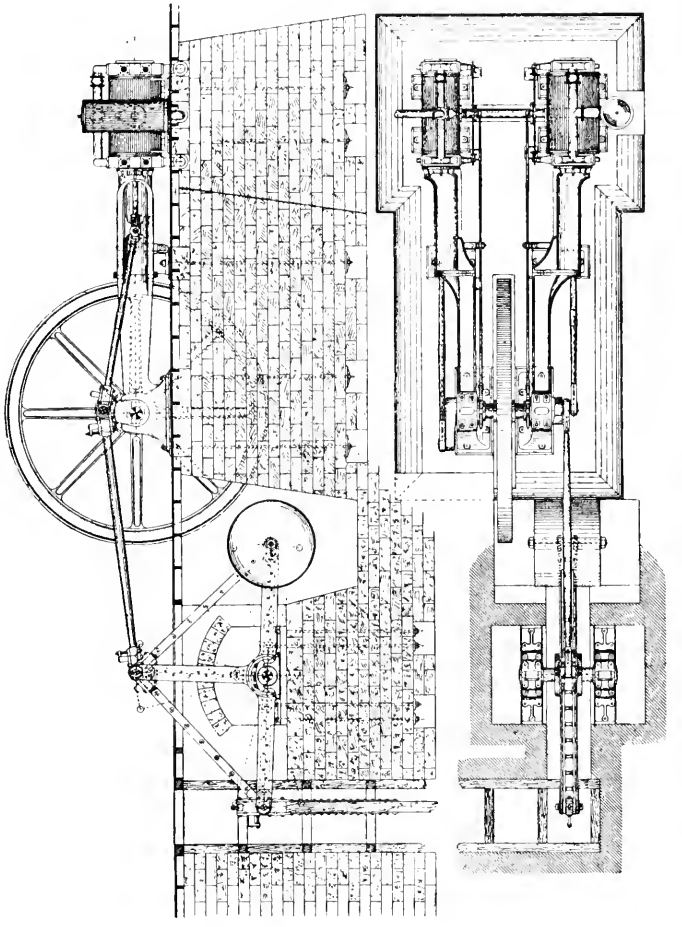


FIG. 82.—DIRECT ACTION COMPOUND CORLISS PUMPING ENGINE.

shown in the drawing, would be a compound condensing engine, such as a horizontal Corliss, by which great economy of fuel could be effected and a high duty obtained. In this case the engine would have a separate house and be fed by two or more Lancashire boilers.

In many cases where there is a supply of water on the surface a large

overshot waterwheel is erected, and the pumps connected direct to a crank on the wheelshaft; or a turbine or Pelton wheel may be used for the same purpose. This, of course, is the most economical arrangement of all.

Direct Action Compound Pumping Engine.—Another class of pumping engines, often called Cornish pumping engines, is the crank and flywheel engine, which in many localities is employed for the drainage of mines. In these engines the length of the stroke is constant, being, of course, determined by the crank, while the flywheel effects the same purpose as the ponderous rods in the Cornish engines—that is, it stores up energy at the beginning of the stroke which afterwards is given out and helps to complete it. These rotative pumping engines, such as that illustrated in fig. 82, have a high rate of duty, regarding which many extremely careful tests have been made.

The arrangement shown in fig. 82 is to be preferred to a geared engine when the total lift or length of pipes exceeds a single line of 10 in. diameter by 6 ft. stroke, raising water from 300 to 400 yds.

The engine is a twin compound horizontal Corliss, with a crank on the low-pressure side of sufficient strength to transmit the entire power of the double engine, and also any excessive strains due to pumping and the method of connection. A double crank pin in the engine crank receives the connecting rod for the pump bob next the crank, and also the connecting rod of the low-pressure engine on the outside. This form of construction permits of the engines being placed as close as possible, thus reducing the width of the foundations to a minimum, and allowing them to be built up in a practically unbroken mass, and requiring proportionately much less expensive foundations than vertical engines.

Almost any form of horizontal engine is suitable to this arrangement, which also offers the advantage of allowing one-half of the engine to be put up first, the other being erected when the pits have been sunk deeper, or the amount of water increased.

The compound condensing engine, such as the one illustrated, is supplied with a condenser of the jet style, and an air-pump not shown in the engraving, which may be of the direct connected type, driven from the cross head or crank pin, or can be of the independent steam pump pattern.

The balance or T-bob, shown in the illustration, is built of Swedish iron, working on a cast iron turned axle. The balance weights are enclosed in a drum of sheet iron, and may be varied according to the amount required to balance the rods.

Direct Acting Steam Pumps.—The next great improvement or departure in steam pumping machinery was the invention of a direct acting steam pump in which there are no revolving parts, such as

shafts, cranks, or flywheels; but in which the power exerted in the steam cylinder is transferred to the plunger or piston of the pump in a direct line by means of a continuous rod. The first pump of this class was invented by the late Mr. Henry R. Worthington in 1840, and was used by him to feed the boiler of a canal boat. Passing over the wearying details of the earlier valve motions, we will briefly glance at the principal points in the development of the direct acting steam pump by Mr. Worthington. First, in the year 1849, certain improvements were introduced by means of which the pumps could be operated by an ordinary slide valve. From this discovery may date the real introduction of this form of pump into general use. The next point to notice is the radical departure from the large valves, having considerable lift, to a number of small valves, each one having but a small area and fraction of an inch of lift, but in the aggregate giving ample waterway; by this means the valves are kept close to their seats; they close quickly without shock, thus enabling greater speed to be attained than it is possible with a single valve, as, for example, that of the Cornish pump. This system of numerous small valves working, as it were, over a grater, forms a strainer which prevents the passage of foreign substances into the pump; another advantage is, that if one or more of these valves receive a temporary or permanent injury, or even total destruction, it would simply impair the efficiency of the pump, and would not render it useless, as in the case of a single-valve pump.

Mr. Worthington applied the compound principle to his direct acting steam pump about 1854; this was easily accomplished owing to the simple construction of the pump. Another cylinder was added in direct line with the plungers and first cylinder. The power developed by both the cylinders was communicated to the plungers by the same piston rod, and in this simple manner the end was accomplished.

The steam, at boiler pressure, was admitted to the smaller cylinder, and exhausted thence behind the piston of the larger on the return stroke; the rate of expansion of the steam being equal to the relation of the one cylinder to the other, and this usually is as 1 to 4.

In these direct acting pumping engines, as also in the Cornish engine, and to a lesser degree in the rotation crank engine, the sudden reversals and reciprocations produced a jar and recoil which increased with the speed; and as slow speed means, in most cases, loss of economy in steam, we find the next improvement in the direction of remedying this defect. The remedy took the form of the Worthington direct acting duplex pump (fig. 83), introduced in 1860,—a pump, which for cheapness of construction, certainty of action, general simplicity of its parts, and entire absence of jar or recoil, has no equal. The duplex pump is really two pumps placed side by side on a common bed plate; the lever which receives motion from the piston rod of one pump actuates

the steam valve of the opposite pump; thus the motion of the piston, instead of operating its own slide-valve—as in the single pump—gives motion to the valve of the opposite cylinder. The valves are so arranged that when each plunger has completed its stroke it makes a momentary pause before restarting on the return stroke. During this pause the valves quietly and noiselessly fall into their seats.

The effect of this arrangement is that the plunger of one pump, having started and taken up the load of the water column, moves on to the end of its stroke, when the plunger of the second pump having started, takes up in its turn the load of the water column. The pumps being each double acting, a steady and continuous movement of the water in the column is the result. This movement is easy in its flow

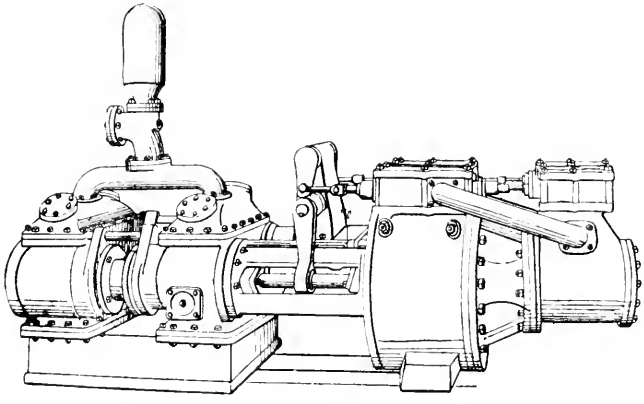


Fig. 83.—The Worthington Compound Packed Plunger Pump.

and absolutely without the noise, jar, and recoil incident to the sudden starting into motion or bringing to rest of a heavy column of water.

The modern type of the Worthington duplex pump, as used for mine drainage, is shown in fig. 83.

The limit of expansion by means of compound cylinders had apparently been attained, with steam at ordinary pressures, in the above-described duplex direct acting steam pump.

Further efficiency from cutting off and expanding the steam in each cylinder by itself could only be gained by storing up energy in the early part of the stroke, and to do this, neither crank, flywheel, nor massive reciprocating parts could be used, as any of these devices well-known would have deprived the duplex engine of its vital points of superiority and merit.

The desired result was, however, secured by a very simple, though highly ingenious attachment, which the makers describe as follows:

The high duty attachment consists, briefly, of two small oscillating

cylinders attached to an extension of the plunger rod of the engine, preferably beyond the water end. These cylinders and their connecting pipes are filled with water or other liquid. Compressed air from a storage tank is admitted at a suitable pressure to maintain a constant load upon the pistons in the cylinders, through the medium of the interposed water. These pistons act in such a way with respect to the motion of the engine, as to resist its advance at the commencement of the stroke and assist it at the end, the air, meanwhile, exerting its unvarying pressure at each point of the stroke.

The two cylinders act in concert, and, being placed directly opposite each other, relieve the cross head to which they are attached of any sliding frictional resistance, and the engine of any lateral strain.

By thus alternately taking up and exerting power through the difference in the angle at which their force is applied with respect to the line of motion of the plunger rod, these two cylinders in effect perform the functions of a flywheel, but with the important mechanical difference that they utilise the constant pressure of compressed air instead of the energy of momentum. Their action is readily controlled, and their power can not only be exactly proportioned to the work to be overcome, but is entirely unaffected by the speed of the engine. The same amount of expansion can be obtained in the same engine whether running at a piston speed of 10 ft. per minute or at 150. This latter feature is one of great importance, affecting, as it does so favourably, the economy of the engine when applied on any service where the demand is irregular or intermittent. Where such service is performed by a flywheel engine it is a well-known fact that the best economic results are attained only when the engine is running at nearly its full rated capacity, and that its economy rapidly falls as its speed is decreased With every change in the rate of rotation of the flywheel a corresponding change in the point of cut-off must be made. When the speed is decreased the steam must be made to follow further in the stroke of the piston, thus reducing the expansion, and consequently the efficiency of the engine.

This high duty attachment enabled the duplex direct acting steam pump to reach as high a duty as ever has been attained by any pumping engine, at a careful, thoroughly authenticated trial,—indeed, these engines have replaced many of the high duty Cornish pumping engines both in Europe and America. The indicator cards shown in figs. 84 to 89 will illustrate the precise automatic and uniform effect of the high duty feature of the Worthington engine.

In all pumping engines there are two completely antagonistic elements to be reconciled, viz., an elastic expanding vapour at one end, and an inelastic non-compressible fluid at the other. In moving the fluid an effect must be obtained as near absolute uniformity as possible, while

to secure the greatest economy of steam expansion it is necessary to produce the widest practicable variation of pressure upon the steam pistons. It is obvious, then, that some means must be provided within the engine to equalise these widely differing demands, and the completeness with which the compensating cylinders of the Worthington high duty engine meet these requirements is plainly shown by considering the steam cards from the engine in conjunction with the action of the compensating cylinders.

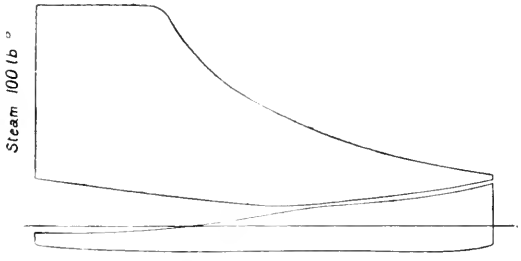


Fig. 84.—Indicator Diagram.

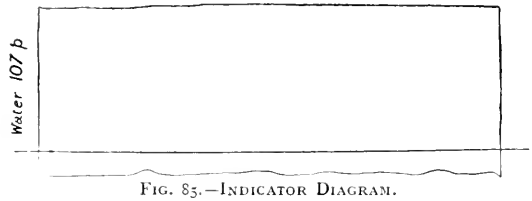


Fig. 85.—Indicator Diagram.

Fig. 84 is an indicator card, with diagrams from both high- and low-pressure cylinders; fig. 85 is a card from the water end or pump of the same engine, these cards being taken from a Worthington 5,000,000-gallon engine in service, running regularly against an average water

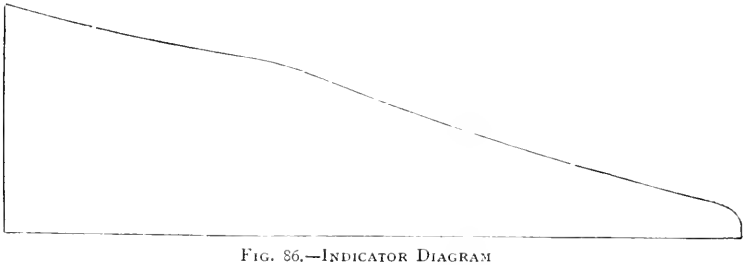


Fig. 86.—Indicator Diagram

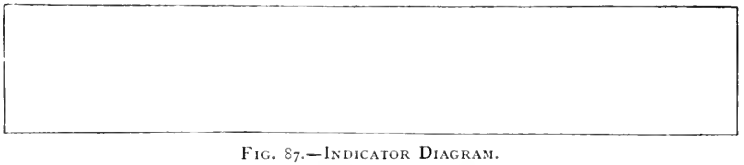


Fig. 87.—Indicator Diagram.

pressure of 107 lb. It will be observed that the variation of pressure in the steam cylinders, as is always the case where high expansion is employed, is *nearly* 100 lb., whereas the card from the pump is *practically*

uniform. Fig. 86 shows the high- and low-pressure diagrams, both reduced to a single diagram based upon the low-pressure piston area, which shows the actual variation in steam propulsion during the stroke. Fig. 87 represents the water diagram reduced to the same scale as fig. 86, and indicates the absolute uniformity throughout the stroke in contrast to the variation shown by the expanding steam in fig. 86.

As explained previously, the action of the compensating cylinders of the high duty attachment is, in effect, to resist the steam pistons the first half of the stroke, and to help them drive the load during

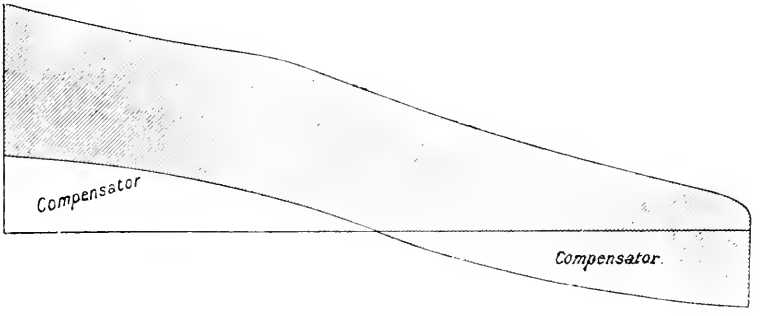


FIG. 88.

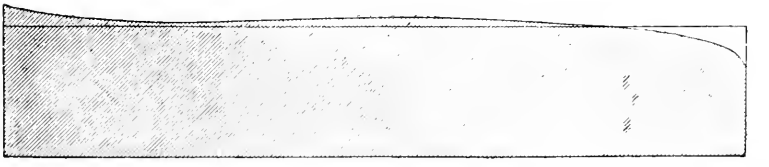


FIG. 89.

the last half of the stroke. Fig. 88 shows how efficiently they perform this important work. The diagram in fig. 88 is formed by overlaying the steam diagram in fig. 86 with a curved line, representing the pressure exerted by the compensators. The shaded portion of the diagram gives the net effect of propulsion derived from the steam pressure upon the engine pistons in conjunction with the action of the compensators. The remarkable uniformity of the combined effort is indicated by the nearly equal width of the shaded portion of the diagram throughout the stroke; and to present a still closer comparison between the propulsive energy of the engine and the demands for uniformity made by the water diagram (fig. 87), we produce fig. 89 by overlaying the water diagram with the shaded part of the diagram in fig. 88.

It will be observed that the propulsive energy indicated in fig. 89 is slightly above the water diagram during nearly the whole stroke, just

enough to cover the friction of the engine. At the end of the diagram (to the right) is shown how the slight momentum of the moving parts of the engine assists in finishing the stroke, until they are arrested in their movement by the cushioning effect produced in the steam cylinders. The indicated energy of the steam power as controlled and distributed by the high duty attachment, showing an almost exact coincidence with the straight line forming the top of the water diagram, explains why the action of the Worthington high duty engine is absolutely smooth and noiseless.

Fig. 90 shows the diagram of the compensator action. The left end of the curve, above A, indicating the resistance to the pistons when the initial steam is in excess of the mean effective pressure; the right end of the curve, below B, indicating the propulsive force of the compensators when the terminal steam is below the mean effective pressure. The lower portion of fig. 90 illustrates the various positions of the compensating cylinders throughout the stroke in forming the curve shown above. The action of this device is an admirable exponent of the principle of the parallelogram of forces; the hypothenuse, or the diagonal of the parallelogram, gradually increasing in length until, at mid-stroke, it coincides with the perpendicular, and the effect of the compensators falls to zero at a point where the mean effective steam pressure is just equal to driving the load, gradually increasing again until, at the end of the stroke, the resultant of the diagonal just makes up the deficiency imposed by expansion. These diagrams will repay a careful study upon the part of engineers and mechanical students.

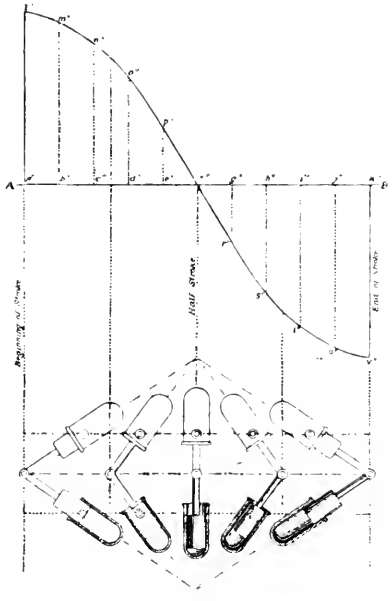


FIG. 90.—DIAGRAM SHOWING ACTION OF COMPENSATOR.

Pumping Engine Tests at Oxford.*—"The success which followed the introduction of Worthington engines at the West Middlesex Waterworks and elsewhere, induced the corporation of Oxford to erect a similar one at their works, and the following statement of a careful trial

* From the *Engineer*, March 6th, 1891.

made by their engineer, Mr. W. H. White, C.E., must be acknowledged as exceedingly good:

Date of trial, Jan. 15th, 1891.
Duration of ditto, 6 hours.
Total number of revolutions, 7301.
Average revolutions per minute, 20·25.
Average total lift, 185·86 ft.
Total pounds of feed water, including jackets, 12,408.
Pounds of feed per hour, 2068.
Total pounds of coal, gross, including ash, 1213.
Gallons pumped per revolution, 100.

$$\text{Pump horse-power} = \frac{100 \times 10 \times 185{\cdot}86 \times 20{\cdot}25}{33{,}000} = 113{\cdot}9.$$

Indicated horse-power—mean of 48 diagrams, 123·34.

$$\text{Pounds of feed per pump per horse-power per hour} = \frac{2068}{141} \text{ including jackets, } 18{\cdot}14.$$

$$\text{Pounds of coal per pump horse-power per hour} = \frac{1213}{6 \times 114} = 1{\cdot}77.$$

Evaporation, pounds of water per 1 pound of coal, 10·2.

$$\text{Efficiency, } \frac{\text{Pump horse-power}}{\text{Indicated horse-power}}, \text{ 92·3 per cent.}$$

Duty, assuming evaporation of 10 pounds of water per pound of coal, as required by contract = 122,000,000.
Duty on actual coal burnt, 125,100,000.

"It will be observed that the pounds of coal as actually used represent a duty of 125 millions, while 122 millions is the duty on an assumed evaporation of 10 to 1, so that the duty actually obtained is almost exactly the same as that calculated."

The above results were undoubtedly very satisfactory, and there is no reason why equally good results should not be obtained from an engine occupied in the drainage of a mine instead of the supply of waterworks. The high duty attachment can be placed upon any Worthington engine, and is shown attached in the rear of fig. 91. During the alteration the pump would not be required to stand idle except for a few days, and as a rule no alteration of the building, original piping, or foundations would be necessary. The change which would result in the duty of the engine would be of at least 50 per cent., representing a saving of fuel of over 30 per cent.

The Worthington pumping engine is largely used at waterworks to pump direct into the mains; it is also used for the more severe and trying service of forcing crude petroleum through pipes from the oil region to the Atlantic seaboard, in some places under a constant head of 900 lb. per square inch.

At one of the pumping stations of the National Transit Company's Oil Pipe Line, Osborne Hollow, there is a Worthington engine pumping 26,000 barrels per day against 900 lb. pressure. The high-pressure

cylinders of this engine are 41 in. in diameter, the low-pressure 82 in. The engine develops about 750 horse-power; the steam pressure used is 100 lb., $\frac{1}{4}$ cut-off, 16 expansions, and the average monthly efficiency of the engine is 100 millions. The high duty attachment of this engine weighs 3500 lb., and with the engine running under 16 expansions, with piston travel of 65 ft. per minute, it is estimated that the compensating cylinders are developing an energy that could not be imparted by a flywheel of less diameter than 40 ft., and weighing 400,000 lb. By this

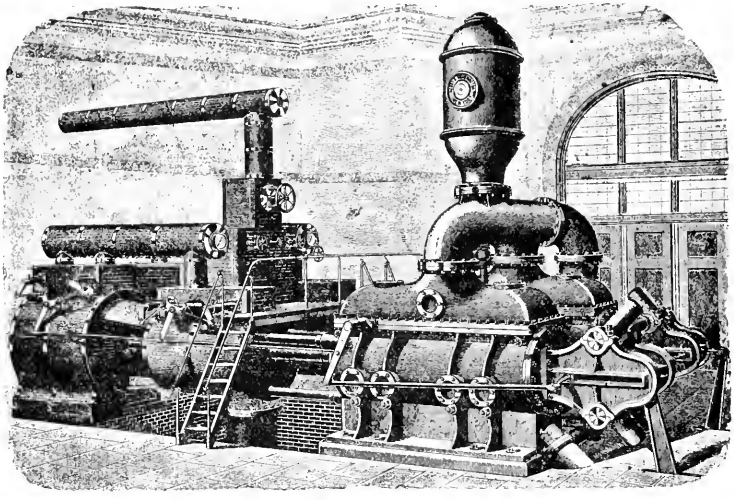


FIG. 91.—THE WORTHINGTON HIGH DUTY PUMPING ENGINE.

one example the difference between the Worthington high duty engine and the flywheel system is made very apparent.

The Riedler Pump.—The principal feature of the Riedler Pump is its mechanically operated valve. The valve and valve seat are circular in form, and made of high-grade bronze. The valve has a lift of from 1 to 2 in., and an area of such amount as to reduce the speed of the water flowing through it but a few feet per second.

At the beginning of the stroke the valve opens automatically, controlled, however, by a very simple and effective mechanical device. It remains open practically the entire stroke. When near the end, it is positively closed at the proper moment by the controller.

The valve opening being large, all throttling of the water through the valve passages is avoided. The mechanical controller, closing the valve at the proper moment, prevents slip and allows the pump to be run at any desired piston speed.

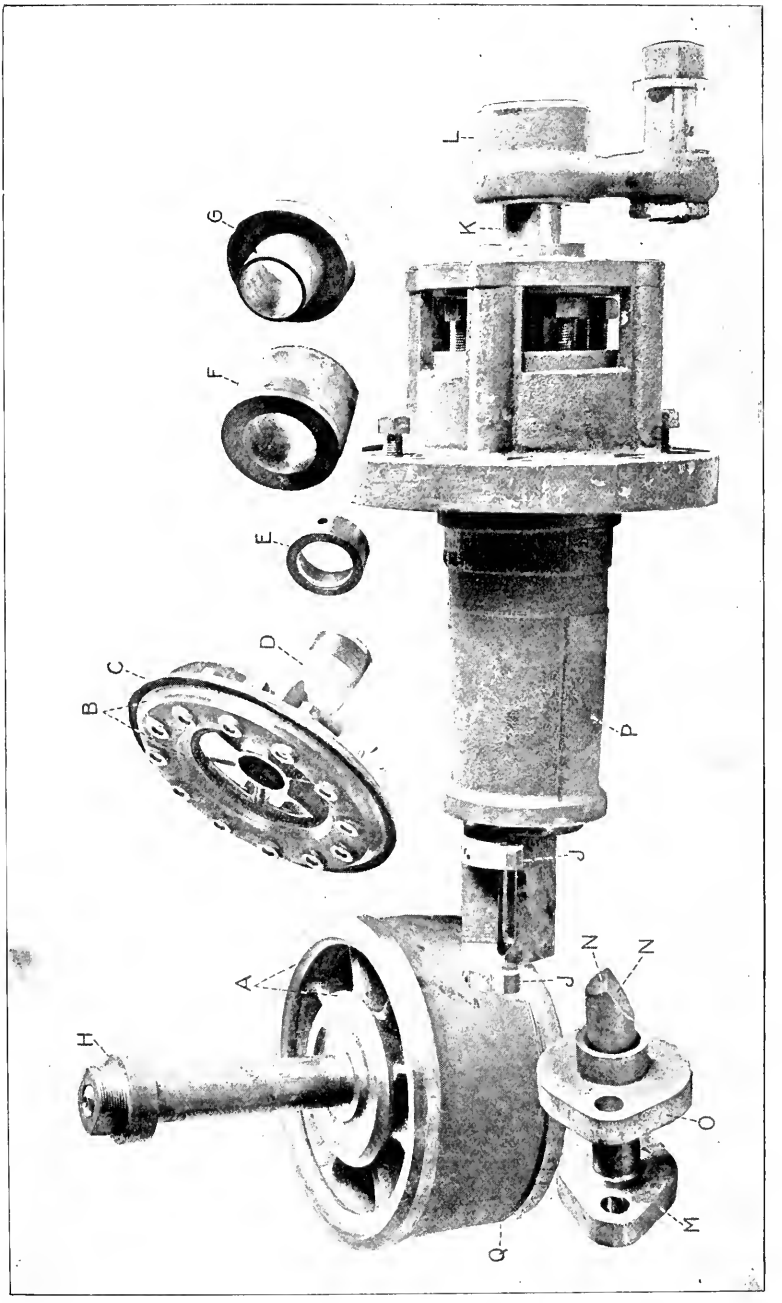


FIG. 92.—THE RIEDLER VALVE, CONSTRUCTIVE DETAILS.

In ordinary pumps there are from 10 to 1000 valves for the suction, and as many for the discharge. Each valve is generally backed by a spring. The loss of power due to the compression of a single spring amounts to but little; but when the large number of valves and the many times they operate are taken into consideration, the loss will be found considerable. The lift of an ordinary valve is but from one-eighth to five-sixteenths of an inch. Owing to the large number of valves, the water is forced to flow through a great many separate and contracted valve passages. This largely increases the friction, due to throttling of the water. In other words, there is less loss by friction in water flowing through a single pipe of large area (as is the case with the Riedler), than there is in the same amount of water flowing through a large number of smaller pipes of the same total area as the large pipe (as is the case in the very best proportioned pumps of other makers). The ordinary pump valves and springs are invariably getting out of order, necessitating frequent repairs with consequent stoppage, as if the pump is not stopped for repairing a single valve, when out of order, it means a large loss by slip, which is of considerable amount in ordinary pumps even with good working valves generally. In the Riedler system there is but one valve for the suction and one for the discharge, and these, because of the mechanical control, work equally well under all pressures.

The details of the construction of the Riedler valve are shown in figs. 92 and 93. The pump to which this valve belongs was made by Messrs. Fraser & Chalmers for the Chapen Mining Company, and has a capacity of 2200 gallons per minute against a head of 1700 ft. corresponding to a pressure of 735 lb. per square inch. On the left is the valve seat with its face marked A, the spindle of the same terminating in the cap (H). Next is the valve proper with its surface (B) and shank (D) through which passes the stem. F is a rubber buffer fitting over the shank (G), which in turn fits over the valve shank (D) and is prevented from slipping off by the cap-nut (E).

The portion of the valve bonnet extending into the valve chamber is marked P. This bonnet contains the packing through which extends the spindle (K) having on its end the forks (J). Keyed to the spindle (K) is the lever (L) through which the spindle receives its motion from the pump wrist plate. The bronze pins (M) have taper ends which bear on the taper on the edge of the valve seat and hold it down in its position. The pins are forced in from the outside, thus doing away with the necessity of work on the inside of the pump body should it be necessary to remove the valve and seat. The glands (O) prevent any leakage around the pins (M). The groove (Q) is used for hydraulic packing. The wedge-shaped metal vanes cast on the valve arms are marked V. These give a slight turning movement to the valve on each opening, and so insure a good bearing at all times between

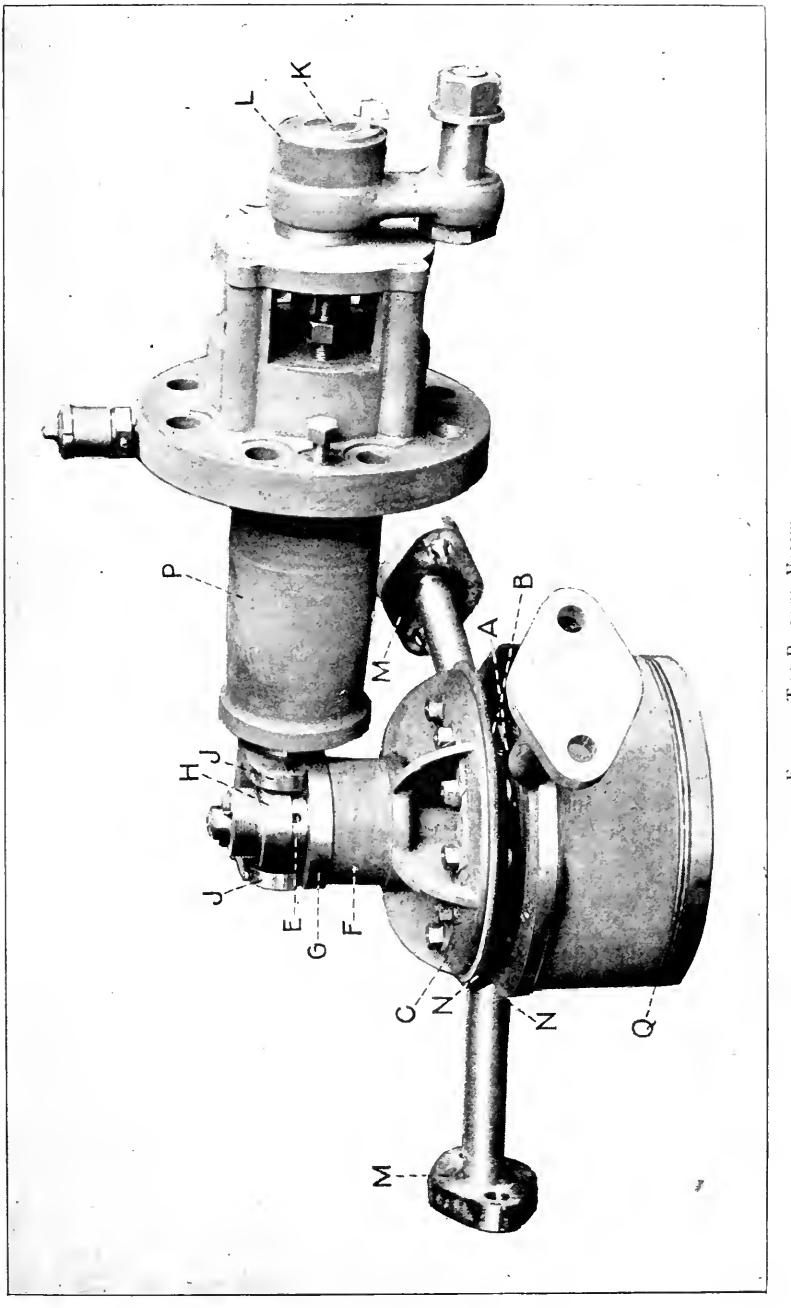


Fig. 93.—The Riedler Valve.

the valve and its seat. It also prevents the severe cutting which might occur in pumps working against high heads, due to grit getting between the valve and its seat. The whole valve is shown fitted together in fig. 93 with the different parts in their relative position for operation, which is as follows.

At the beginning of the suction stroke the valve opens automatically, controlled, however, by a mechanical device. Near the end of the stroke the forks on the end of the shaft move downwards, and before the plunger starts on its return stroke close the valve, thus preventing all slip and pounding of the valve so common on ordinary pumps.

In case of obstruction between the valve and its seat the rubber buffer will be compressed, and thus prevent injury to the mechanism. The work required to close the valves is very little, and the valve mechanism is worked by means of an eccentric on the main shaft or from a prolongation of the slide valve rod as in fig. 95.

It is well known that a high piston speed in steam engines results in the greatest economy of working, and that it is because of this advantage that nearly all the engines used in large manufacturing plants are designed for piston speeds varying from 500 to 1200 ft. per minute.

It was not until the introduction of the mechanically controlled Reidler valve that the advantage of higher piston speed could be safely used in hydraulic machinery. By using this simple but effectively constructed valve the engine may be designed for its most economical piston speed, and the pump plungers then proportioned to suit. This permits a start being made with the greatest possible efficiency in the prime mover of a pumping engine. For normal running, the piston speed is what it should be for an economical engine, and when working at half capacity it is still sufficient to secure fair economy.

Another great advantage of the Reidler pump, due to the high number of revolutions it can safely be run, is the maintenance of a continuous flow of water, both in the suction and discharge pipes. On account of the greater number of revolutions, less water is pumped per stroke. The strokes following each other in rapid succession, keep the water continually in motion, preventing the severe "water hammer" so common in the discharge pipes of others.

The valves are easily accessible. In case of obstruction between valve and valve seat, by a very simple device, all injury to mechanism is avoided. From a record of over 1500 pumps, the average life of these valves has been found to be about five years.

What is gained by high piston speed, made possible by the mechanical valve control, is efficiency of steam, durability, simplicity, and accessibility of mechanism; freedom from severe hydraulic shocks and strains, efficiency of operation between wide limits of speed and consequently capacity; practically no throttling of water, and no slip.

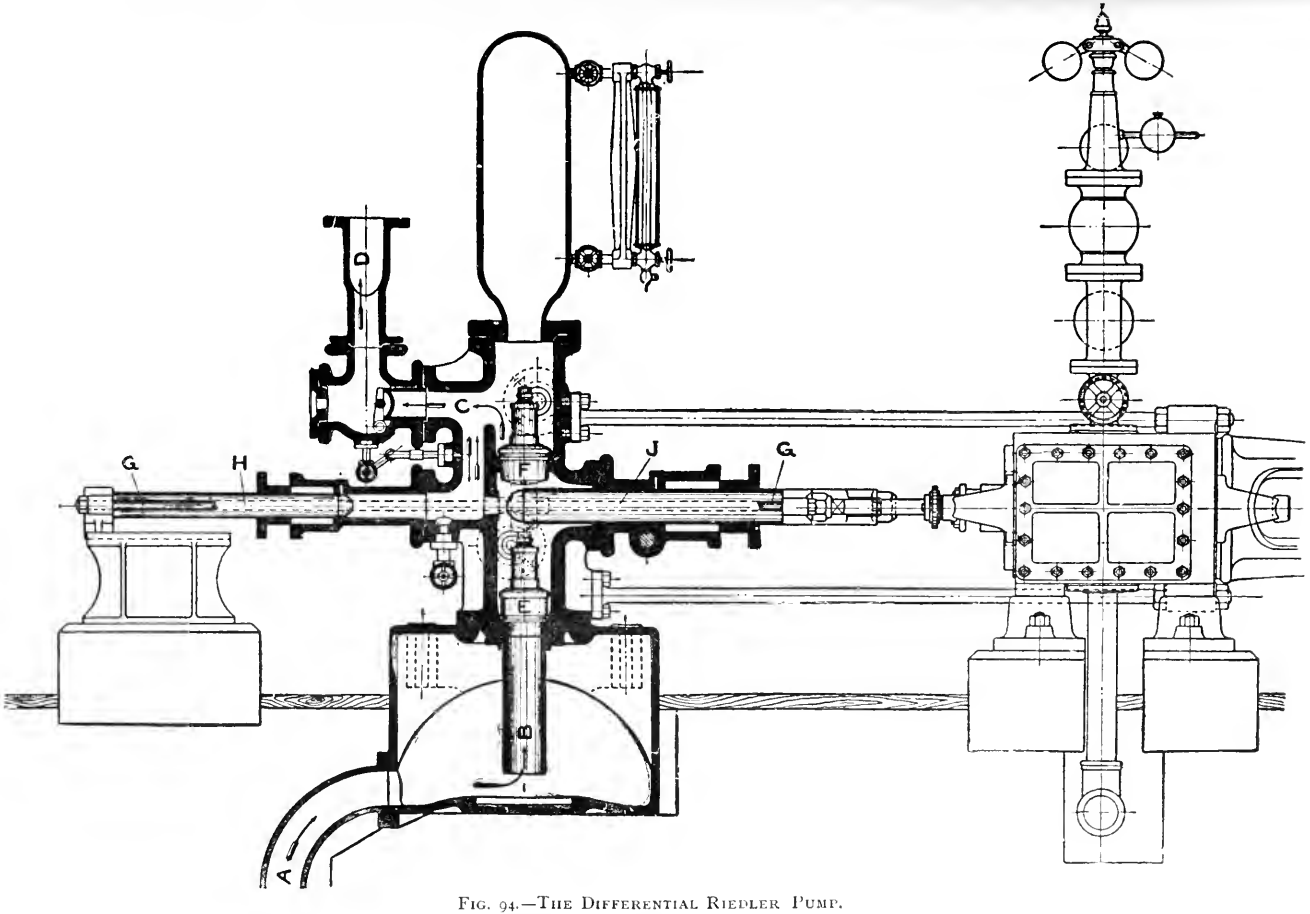


Fig. 94.—The Differential Riedler Pump.

Differential Riedler Pump.—A differential pump is practically a double acting pump with but two valves. By an arrangement, as shown in fig. 94, it will be seen that an equal amount of work is done on each side of the steam piston during one revolution. In a single double acting pump four valves are required, one suction and one discharge valve for each end of the double acting plunger. A single differential pump, however, requires but one suction and one discharge valve for but one of the plungers, the main plunger. The differential pump has the advantage of always being primed, as will be seen by referring to diagram, where the column pipe (D), the discharge space (C), and the differential plunger chamber are always in connection. Thus, the total pressure due to water head is always on the differential plunger (H). In other words, as long as there is water in the column pipe the pumping engine will always have a resistance to overcome even should suction be lost. The arrangement, therefore, prevents undue severe hydraulic strains on the different pressure parts.

Because of having half the number of valves, this form of pump is simpler than the double acting pump, and is used until the capacity becomes so great that the valves would be too cumbersome. When this capacity is reached it becomes necessary either to make a duplex or triplex differential, or to use a double acting pump instead. The double acting pump valve would be half the size of the differential pump valve for the same total capacity. When pumping against high pressures, the air chamber is made of seamless structural steel, or flange steel, so as to prevent leakage of air.

Referring to fig. 94, the water enters the suction pipe (A), passing into the suction air chamber and thence into the suction funnel (B). It should here be noted that the large casting (which acts as a substantial base for the pump) and the suction funnel (B) form in the upper part of this casting a large suction air chamber insuring efficient action of the suction valve (E). When the main plunger (J) moves towards the right, it draws a volume of water equal to its displacement through the suction valve (E). On its return stroke to the left, the suction valve having been mechanically closed, it forces a volume of water equal to its displacement through the discharge valve (F), half of this water passing out into the column pipe (D), the other half passing down and following the differential plunger (H). The discharge valve (F) now being closed, the main and differential plungers which are connected by means of side rods move again to the right, the main plunger drawing the water through the suction valve (E) and the differential plunger displacing its volume and forcing the same through the discharge passage (C) into the column pipe (D).

The cross sectional areas of the main and differential plungers (J and H) are generally made in the proportion of about 2 to 1 so as to equalise the work done on both the forward and return strokes. The side rods (G)

connect the cross heads of the main and differential plungers and are always in tension, and in large pumps are furnished with a cast iron guide.

It will be noticed that in front of the discharge (c) and connecting to the column (D) there is a clack valve. This is for the purpose of holding

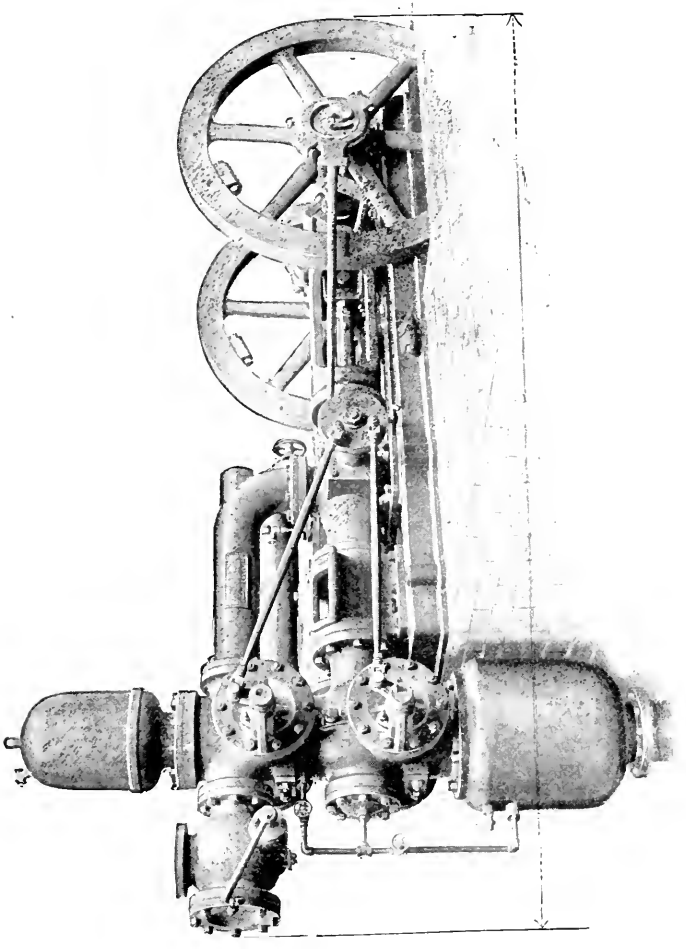


FIG. 95.—DUPLEX SINGLE ACTING RIEDLER PUMP.

the water in the column pipe when it is desired to take out the valves or examine the interior of the pump. A clack valve is preferred for this purpose as it will open automatically when the pump is restarted, whereas if a stop valve were used it might through carelessness be left closed and so cause damage to the pump.

The Riedler pump can be driven either by steam, air, water, or electricity. At the Niagara Falls Water Works there is a Riedler driven by direct connection with a Pelton wheel, the buckets of which are placed around the rim of the flywheel on the crank shaft. This pump has a capacity of 6,000,000 gallons per 24 hours against a head of 358 ft. In other cases an electric motor is placed direct on the crank shaft, thus avoiding all intermediate gearing. If a high-speed motor is used then gearing or belting is necessary, but this is less costly than the direct method.

In fig. 95 will be found a general idea of the arrangement of a duplex single acting Riedler pump. This pump is so arranged that it can be run either by steam or compressed air, and the change can be made in a few minutes. The engine is a horizontal cross-compound non-condensing slide valve running at a speed of 635 ft. per minute, and the pump has a capacity of 750 gallons per minute against a head of 635 ft.

Air-Driven Pumps.—In many mines it is a great inconvenience, or even source of danger, to run long steam pipes for conveying steam to operate underground pumps or hoists. Often the pipes required are of considerable length and not properly covered. The result is the addition of much heat in the shaft, which not only is annoying, but tends to rot the shaft timbers. With well covered pipe, however, this difficulty can be entirely overcome.

Where the use of steam is not desirable, electricity or (preferably) compressed air can be used. Compressed air has the advantage of safety, and after having done work, the exhaust air aids in the ventilation and cooling of the underground compartments. In all mines it is necessary to install a compressor plant to operate air drills. To make this compressor of size large enough to in addition run by compressed air all other underground machinery, will increase the cost comparatively but a small amount.

In case the greatest economy is desired, air re-heaters can be used. In fact compressed air in conjunction with proper air re-heaters is at present the most economical transmission power.

The most convenient method of re-heating air in mines is by steam. A small, well covered steam pipe may be led to distances as great as 10,000 ft., or even more if required, to the point of installation of engine to be run. At this point the steam can be properly conveyed through an air re-heater, raising the temperature of the air to within a few degrees of the steam temperature. The steam pipe being small, practically no inconvenience from heat arises. It absolutely causes no inconvenience if "ordinary good care" is taken in covering the pipe. Re-heating stoves and furnaces for heating both small and large quantities of air under pressure can be readily obtained.

Mine Drainage.—*General Remarks.*—In providing for the drainage of a mine, there are, after fixing upon the capacity and lift, two things chiefly to be borne in mind. First, the commercial efficiency of installation considered with due reference to the mining risk and the length of time that the plant will probably be in use. Second, the safety against "drowning out" that the plant should afford.

In the first place, the capacity of the pumping plant should be determined by proper measurements with ample reserve capacity allowed for emergencies. This point cannot be too carefully considered, as upon it may depend the entire welfare of the mine.

The best safeguard against flooding a mine is the installation of a pumping plant of ample capacity.

At one time the Cornish pump was held in great favour because in the event of drowning out, the pump could still be operated from the service, but it was not durable, was inefficient, and cost a great deal to install. Upon the introduction of the Riedler pump, with its great economy and durability and its arrangements as to safety, many Cornish pumps have been replaced, and few, if any, are now being installed.

Where a very large quantity of water is to be raised, it is often well to install a duplicate plant, either one of which will handle the water under normal conditions, so that in case of flooding both may be run. The life of a plant of this kind is greater than in a single pump plant where the machinery must run continuously year in and year out.

In determining the general type of a plant, after having determined the capacity and lift required, the next important thing is obtaining the necessary power.

In case a water-power of sufficient amount is available, the problem becomes a very simple one—when the water-power is scant, the problem becomes very complicated and apparatus of the highest efficiency must be used so that little or none of the available power will be lost. The pumps may be run either by compressed air or electricity, whichever power is preferable depending upon local conditions, such as distance of power from pumping plant, fuel conditions, and machinery to be run. Where water-power is not available, steam-power must be adopted. Here the cost of fuel is the first consideration in determining the type of engine that is to be used. In most mining camps fuel is generally very expensive and therefore none but the most economical machinery should be installed.

The boiler plant should be made up of as large units as possible, there being allowed at least one reserve unit for use in case of emergency or to permit cleaning or repairing of the other units. If possible the furnaces of boilers should be so arranged as to permit use of the different fuels that may be obtained in the locality, as thereby competition of the different fuel dealers may be taken advantage of in securing most favour-

able rates. The price of fuel is generally higher, the greater its efficiency. Transportation, however, is generally the same per ton over the same route, so the higher grade the fuel, the cheaper is freight; but as prices vary, the conditions may change and it is therefore well always to be prepared to take advantage of the market.

A boiler plant should always be of ample capacity so that forcing is not necessary to furnish sufficient steam for machinery when running normally. This tends to greater efficiency and durability of the plant.

In all cases suitable feed-water heaters should be installed, as they always tend to increase the efficiency and prolong the life of the boilers.

A few years ago it was the custom to install rough and ready machinery that consumed from five to ten times the amount of fuel that would have been used had better machinery been installed. Now it is customary, as engineers and business men appreciate what is meant by economy and the large saving that can be made in fuel handling and repairs, to install high grade pumps driven by compound or triple expansion condensing Corliss engines.

The type of pump to be used depends upon the size of the shaft, which determines the size of the parts,—the character of the rock, which determines the size of the pumping station,—and consequently the type of pump; and the facilities for transporting and lowering the parts of the machinery which will determine the weight of the heaviest piece. Whether it will be better to pump the water from several different levels or to collect it all in one sump and use one pump to force it all to the surface can only be decided when the quantity and conditions at each mine are known.

CHAPTER VI.

PUMPING ENGINES (continued).

Sinking Pumps—Essential Conditions—The Cameron—The Worthington—The Deane—The Pulsometer—Station Pumps Underground—The Worthington Condenser—Relative Efficiency of Station Pumps—Choice of Pump—High Duty Pumps in Mines—Comparison with Direct Acting and Cornish Pumps—Relative Cost of Pumping Plants—Pumps for Mill Work—The California—The Duplex—The Centrifugal—Pump for Tailings—The Tailings Wheel—Memoranda Relating to Pumps.

Two general classes of direct acting steam pumps are used in mine drainage—the sinking pumps, designed to work vertically, and the station pumps, which are designed to work horizontally. The sinking pump should be of as compact a form as can possibly be devised, having all the valves easily accessible, and valve and piston rods protected from flying stones, resulting from shots. We might summarise the requirements of a good sinker: (1) compactness, so as to occupy the minimum space in the shaft for the maximum quantity pumped; (2) strength to resist hard blows and rough usage, incident to a machine that must be kept steadily at work, at points within 20 ft. of the shaft bottom; (3) economy. This is placed last, because it is of least importance. The sinking pump is naturally of a temporary character, and is replaced by a station pump when the shaft is completed, therefore the pump that can stand hard knocks, and occupy the smallest space for a given pumping capacity, must be the most efficient as well as the most economical in the long run. In shaft sinking a few minutes' stoppage of the pumps may often cause an hour's delay, to drain the water, so that the men can resume sinking.

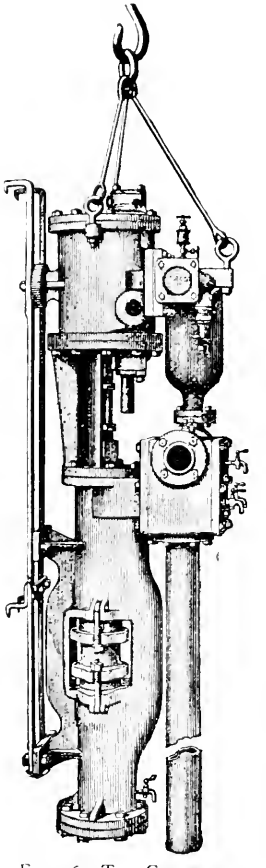


FIG. 96.—THE CAMERON PATENT SINKING PUMP.

The first principle involved in the application of direct acting steam pumps in mines, is to have a continuous acting machine—one that will never stop for repairs or renewals and consequently cannot be drowned out, with the ordinary flow of water that it is designed to handle. As no machine, however perfect, can fill these conditions, the only solution is to have two pumps, one working, and the other in perfect order, ready to start up immediately steam is turned on. This we shall designate the duplicate pumping system, repeating that it is the only safe and reliable method to pursue, whether it be in the sinking pump draining out an old mine, or sinking for a new one, or lastly, in the station pump for the permanent drainage. In each case the pumps must be in duplicate, so as to ensure constant work.

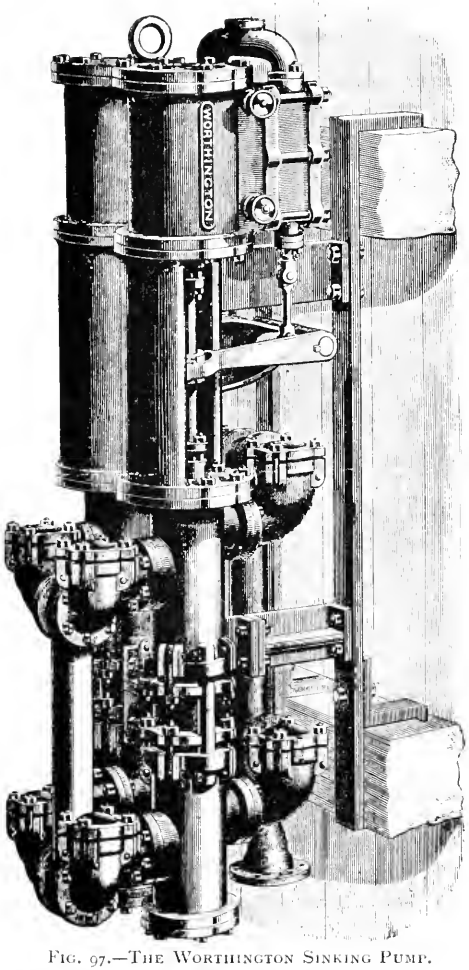


FIG. 97.—THE WORTHINGTON SINKING PUMP.

The Cameron sinking pump (fig. 96) is the one in more general use in the mines of the Western States; while the Deane (fig. 98) and the Knowles, are not used as extensively as they might be, but are being gradually introduced.

The Worthington Sinking Pump. — The sinking pump, shown in fig. 97, is designed to work vertically in sinking mine shafts, recovering flooded mines, and for mine pumping work requiring the use of an efficient steam pump, which shall be positive in its operation, quiet in action, compact in its design—thereby occupying the least possible amount of space—and built in the strongest manner, so as to withstand the hard usage to which pumps on this service are, as a rule, subjected.

The water plungers are double acting, working through exterior stuffing boxes and adjustable packing. Means are provided, as will be seen, for either suspending the machine at the link shown on the ends of the steam cylinders, or for hanging it on timbers on the sides of the shaft.

The suction opening is at the lower end of the pump, which is the most convenient place for attaching the suction pipe or hose. The discharge connection to column pipe is on the side. The water valves are inclosed in heavy pots, and are made accessible for examination or repairs by means of swing bolt-covers on the valve pots.

The fact that this pump is duplex, and fitted with the Worthington valve motion makes its operation positive. It is always ready to start and when running there is an entire absence of the concussive action which results from the use of single pumps, and which often causes serious trouble and annoyance by bursting the column pipe. Being self-contained and working with perfect smoothness, the strain on supports and hanging irons is, of course, reduced to a minimum.

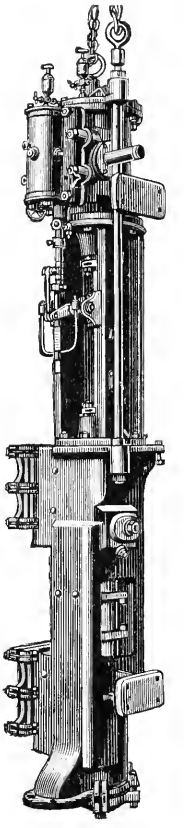


Fig. 98.—The Deane Sinking Pump.

The Deane Sinking Pump.—This pump, which has already been referred to, is illustrated in fig. 98. It may be slung on chains, as shown, or temporarily hung on to a bearer. The steam is supplied from the surface under a pressure of 50 lb.; and a pump having a steam cylinder 18 in. diameter, with a bucket of $18\frac{1}{2}$ in., plunger of 13 in., and a stroke of 24 in., will raise 500 gallons per minute, to a height of 150 ft. The same pump with certain modifications, will raise 7000 gallons per hour to a height of 200 ft.

The valves are so constructed as to be easily accessible, and the water passages large and direct, so as to offer but little resistance to the flow of water. The objection to steam pumps for sinking operations is the exhaust steam; but, if desired, a special condensing arrangement can be attached, which will do away with this difficulty. For very gritty water a special pump can be obtained, with valves adapted to the circumstances. The pumps are all strongly made, and but little liable to get out of order.

The Pulsometer.—Another form of pump, which is preferred by many for shaft sinking and kindred purposes, is that known as the "Pulsometer," an invention which is in fact a perfection of the principle of Thomas Savery, in 1698.

The pump is shown in fig. 99, and in section in fig. 100, and, as now constructed, consists of a hollow chamber, called the body, composed of two pear-shaped castings forming water chambers, with their necks joined above, between which is the air vessel, while the discharge chamber is at the lower end of the body; to which, in fig. 99, will be seen attached the rising main of wrought iron pipes. The steam arrives by the flexible hose, and, the steam valve being opened at K (fig. 100), the steam passes into that chamber (A) which is not closed by the ball (I) at the apex of the pump, and gently depresses the water without agitation, forcing it through the discharge valve into the delivery pipe. The moment that the water uncovers the passage leading into the discharge chamber, the steam passes underneath the water, and is suddenly condensed, forming a vacuum which draws the ball valve over, thus shutting off the steam from one chamber and allowing it to pass into the other. The vacuum at the same time opens the suction valve (E) and draws the chamber full of water from the suction pipe; meanwhile, the steam is emptying the other side of the pump; and so the action goes on surely and regularly, without intermission, so long as steam is supplied, and there is water to be pumped. The change from one vessel to another is so rapid that, even without an air vessel on the delivery, but little pause is visible in the flow of

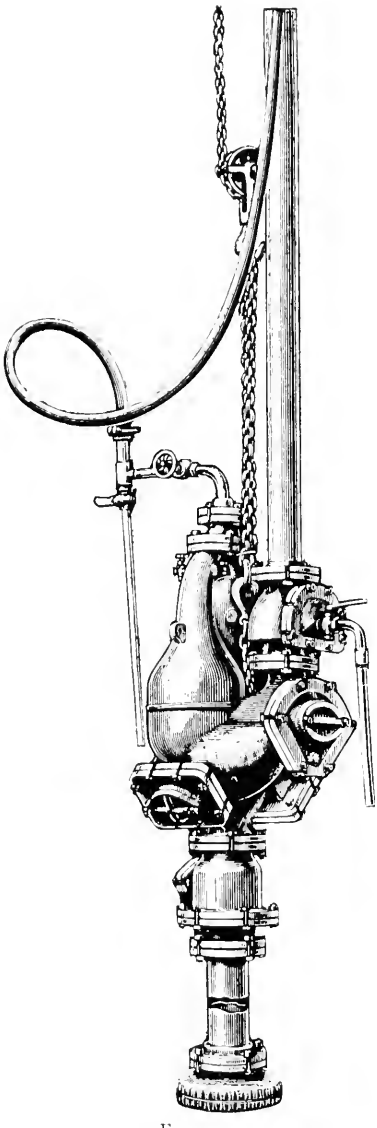


Fig. 99.
The Pulsometer Sinking Pump.

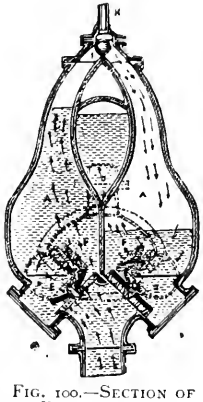


Fig. 100.—Section of the Pulsometer Pump.

the water, and the stream, under favourable circumstances, is nearly continuous.

There are only five moving parts—the steam admission valve, the two suction, and the two delivery valves; and as there are no complicated internal parts, the pump is very suitable for working with water mixed up with grit, as in sinking or draining levels which have been flooded. The pump can be slung by a rope or chain in the shaft, being raised or lowered as required, while in the case of a recent sinking in a Scotch pit, three sets of three pulsometers were used, one set lifting to the other, and the whole suspended by chains, the entire arrangement working very satisfactorily. As the steam is condensed within the pump for suction purposes, there is consequently no exhaust, a fact which of itself is an advantage in confined situations.

The pulsometer will raise water to heights of from 70 ft. to 80 ft., and draw from about 10 ft. to 12 ft. The steam pressure for lifts of from 20 ft. to 40 ft., should not be less than 20 lb. to 30 lb. per square inch, and from lifts of from 40 ft. to 80 ft., not less than from 30 lb. to 50 lb.

In the simple pulsometer it is impossible to obtain an expansive action of the steam, because the upper valve, whether a ball or other contrivance, must, from its construction, be allowing the steam to pass into one or other chamber during the whole time the pump is at work. Where the work is constant, and there is a good margin between the pressure of the steam and the pressure of the water in the column, a patent automatic cut-off attachment called the Grel may be employed with advantage, especially to pumps larger than the size known as No. 4. An economy of from 40 to 50 per cent. of the total steam consumption is said to be effected by this arrangement, which depends upon the employment of a secondary cut-off valve, in addition to the distributing valve, which admits of a long interval between each pulsation, during which no steam can pass through the steam pipe, although the work of pumping continues.

The pulsometer is made in sizes capable of raising from 900 gallons to 80,000 gallons per hour, at prices varying from £8 to £170.

Station Pumps.—There are many excellent pumps made by various manufacturers in America specially designed for underground station work, all having and combining several good qualities. In the large mines the Worthington and Knowles duplex pumps are the more extensively used, especially by those persons who can distinguish between a good pump and a cheap pump, and also the Riedler.

The style of station pump in most general use is the duplex compound condensing; the condensing apparatus being a separate and distinct pump.

The Worthington patents being still in force, the duplex condenser made by this company is the only one obtainable, the other pump-makers being obliged to content themselves with a single pump condenser, with their uncertainty of action and associated evils.

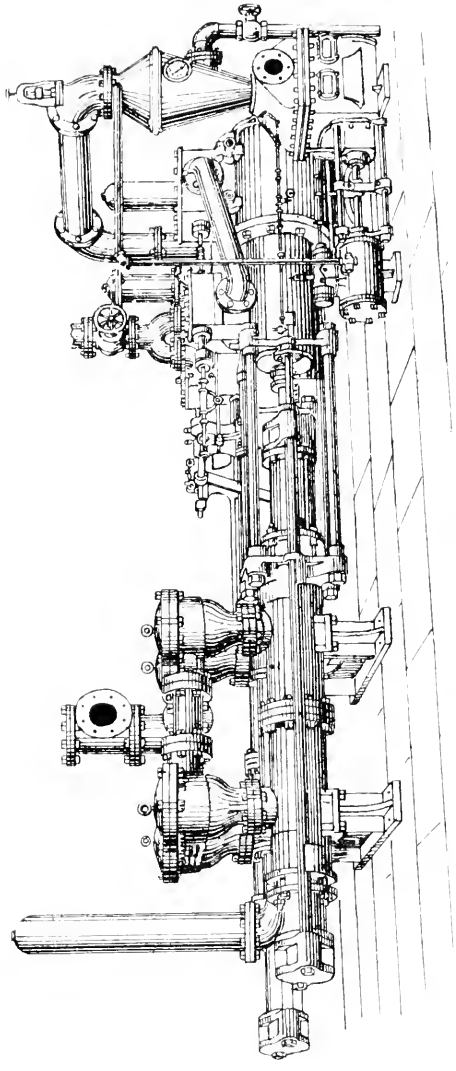


FIG. 101.—KNOWLES PATENT COMPOUND CONDENSING DUPLEX MINING PUMP WITH INDEPENDENT AIR-PUMP AND CONDENSER.

The Worthington condenser consists of a duplex pump and an injector condenser as illustrated in fig. 101, and is so arranged that the momentum of the incoming injection water and exhaust steam is employed to assist the pump in maintaining the vacuum in the condenser. As a direct effect of this combination, the vacuum in the pump cylinders is less in degree than that obtained in the injector condenser and exhaust pipe.

Consequently the load upon the pump is lightened, and the cost of producing the vacuum is materially reduced. In all other type of condensers and air-pumps the vacuum in the pump cylinders is necessarily greater than that in the condensing chamber.

The valve motion is a prominent feature of the condenser. To it is due the complete exemption from noise or concussive action. The two pumps are placed side by side, and so combined as to act reciprocally upon the steam valves of each other. One piston acts to give steam to the other, after which it finishes its own stroke and waits for its valve to be acted upon before it can renew its motion. This pause allows all the

water valves to seat quietly, and removes everything like harshness of motion.

As one or the other steam valves must always be open, there can be no dead point. The pump is therefore always ready to start when steam is admitted, and is managed by simply opening and shutting the throttle valve.

A longitudinal section of Worthington condenser is shown in fig. 103. A is the vapour opening, to which is connected the pipe that conducts to the apparatus the steam or vapour that is to be condensed, and in which a vacuum is to be made and maintained. The injection water used to produce the condensation of the steam or vapour is conveyed by a proper pipe attached to the injection opening at B.

Over the end of the spray pipe (C) is placed a cone, provided with wings that thoroughly separate and distribute the water and insure its complete admixture with the steam. This cone is adjustable by means of a stem passing through a stuffing box at the top of the condenser. Any floating material that can pass an ordinary strainer will not lodge around this cone; but should it become obstructed from any cause, it can be washed clear by simply lowering it by means of its stem.

These condensers are very efficient, and, being self-acting and entirely separate from the main pumping engine, they can be started first, so that the main pump can commence with a normal vacuum at the first stroke; whereas with the condenser attached to it, the main pump must start against the full atmospheric resistance and make many strokes before a normal vacuum is secured.

Triple expansion duplex station pumps are also in use in the mines, and in some cases are preferable to the high duty pumps; in fact, the high duty attachment, already described on page 122, is seldom used in America unless the pump is to develop at least 80 horse-power. In England, however, the high duty attachment is sometimes used on pumps developing as low as 30 horse-power.

Lastly, the high duty Worthington pumps are also used in mines. These pumps have already been described, and are undoubtedly the most useful and efficient, as well as the safest, pumping engine ever introduced for mine or for waterworks service.

Coming to the relative efficiency or duty of these three classes of station pumps. I recently submitted to one of our principal manufacturers a proposition involving the delivery of 500 gallons. (American) per minute, against a head of 3000 ft., and in reply was informed that a compound condensing pump would consume about 1370 lb. of coal per hour; a triple expansion pump 1060 lb. per hour; while a high duty Worthington pump would consume but 840 lb. per hour.

The estimate was based upon the use of high-class boilers which would furnish steam slightly superheated, and with the best class of

coal. It will, however, serve for a basis of comparison. Taking, then, the compound condensing pump as unity, we find that the triple expansion gives a saving of 22·63 per cent. of the coal, and the high duty Worthington a saving of 38·68 per cent. of the coal used in the compound condensing pump. Or, taking it in the reverse order, the coal used in the high duty engine is as 1 to 1·26 in the triple expansion, and as 1 to 1·63 in the compound condensing engine.

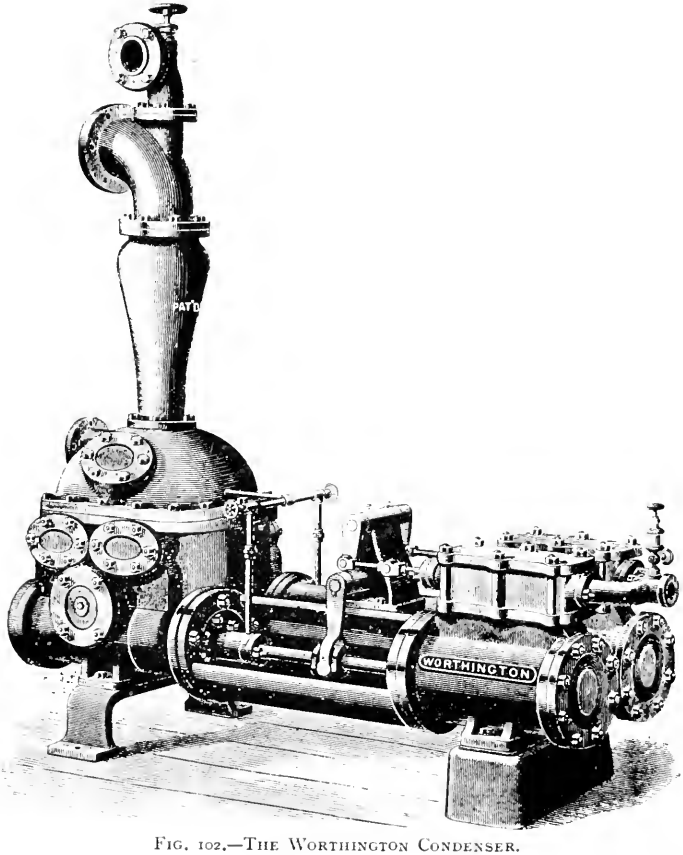


Fig. 102.—The Worthington Condenser.

In deciding on the sort of pump to adopt for any particular mine, the engineer has to take into consideration, first, the possible life of the mine; second, the cost of fuel; and third, the difference in price of compound condensing, triple expansion, and high duty pumps—delivered on the mine, or, better still, erected in place in the mine. The extra cost of the better class of pump must be charged with a minimum interest of 10 per cent. per annum. Taking these various

points into his calculations, the engineer will arrive at the conclusion that for the majority of Western mines the compound condensing pumps are all that is required; while for shaft sinking and general prospecting work, even compound condensing pumps can be advantageously replaced by the very extravagant high-pressure pump.

In deep mines of a permanent character, however, and in places

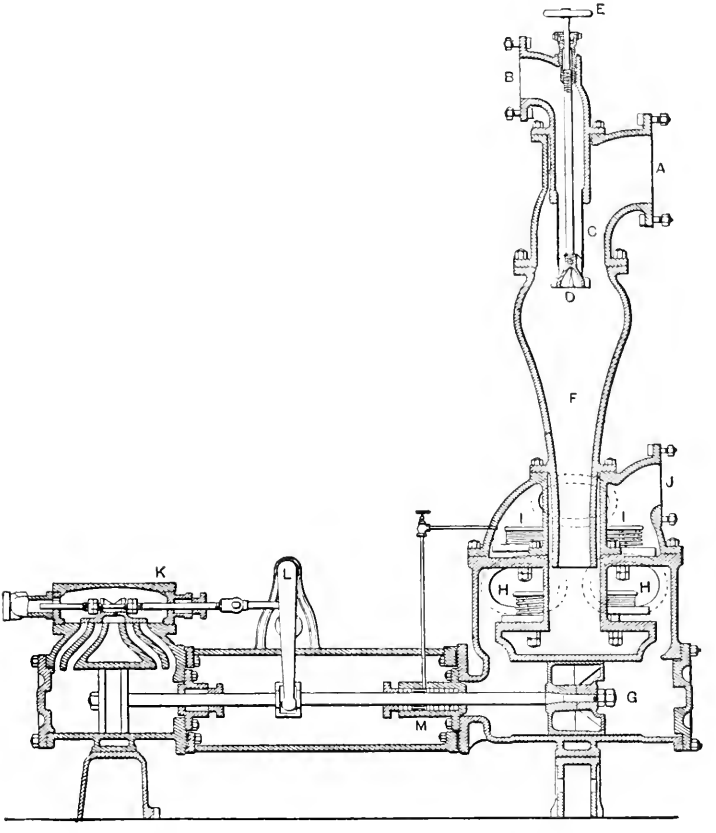


FIG. 103.—SECTION OF THE WORTHINGTON CONDENSER.

where fuel is dear, the best classes of triple expansion and high duty Worthington pumps are in order.

High Duty Pumps in Mines.—We have seen that in waterworks the Worthington high duty pump can easily do 110,000,000 duty under dinary service conditions. The same duty can be obtained in a similar pump placed in the station of a mine, less, however, the power

lost in conveying the steam from the boilers at the surface to the pump below, and this loss with the best non-conducting pipe covering is very small, and is in fact much less than the loss in friction conveying power by means of rods, as in the Cornish system. In this connection we may quote the experiments made in actual practice. At the Wolftone Mine, Leadville, Colorado, steam was conveyed 600 ft. through a 5-in. pipe, covered with 1 in. of hair-felt composition to the pump station in the mine.

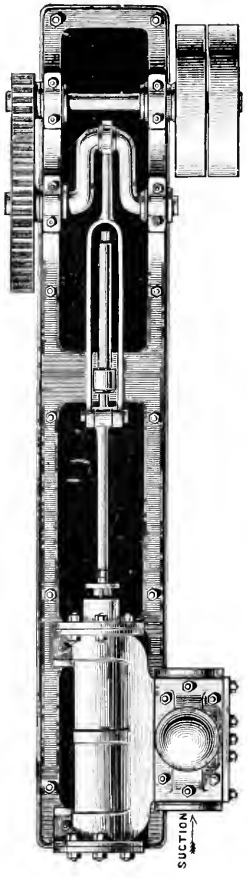


FIG. 104.—PLAN OF THE CALIFORNIA PUMP.

It was found by carefully conducted experiments that the condensation amounted to 100 lb. per hour. The full capacity of the pipe with steam at 80 lb. pressure, and the velocity of 50 ft. per second is 4804 lb. per hour; therefore the loss by condensation is a little over 2 per cent. of the steam used in the pump. It follows that with the pipe used only at half its capacity the loss would be about 4 per cent., or, in other words, 4 per cent. more fuel. The loss in pressure was very slight. Taking these figures as a basis we find that a high duty engine of a similar capacity to the Wolftone pump would at surface develop, say 100,000,000 ft.-lb.; at 600 ft., 2 per cent. less, or 98,000,000 ft.-lb.; at 3000 ft., 10 per cent. less, or 90,000,000 ft.-lb. The advantages claimed and usually admitted on behalf of the Cornish engine are (*a*) economy of fuel; (*b*) safety from flooding; (*c*) reliability in action. To get these points, enormous first costs are entailed to purchase and erect the ponderous machinery, while the cost of repairs and ordinary wear and tear are also heavy.

In comparing these points of advantage with the direct acting steam pumps: (*a*) we have seen that the high duty Worthington pump is more economical than the Cornish engine and is replacing it rapidly in England; (*b*) while it would appear that the Cornish engine itself, situated at the mouth of the pit, is absolutely secure against flood; yet seeing that the strength of a chain is but that of the weakest link, and that the plungers at the various levels are very essential parts of the engine, a stop to repair any of the plungers or other parts of the engine must result in a temporary flooding of the mine,

interfering with the progress of shaft-sinking or work on the bottom level; while a serious accident to the bottom lift of pumps in a mine may cause great delay and often necessitate the lowering of a new lift of pumps to drain the mine again. It is seldom that we find a Cornish pumping engine, in ordinary work, with more than one-third of its total capacity in reserve. Let us assume that an engine has to raise 300 gallons per minute in order to drain a mine, and in case of need can lift 450 gallons steadily without unnecessary risks. We have seen, however, that the direct action steam pump must be in duplicate, each pump having, say, one-third of its capacity in reserve; therefore, while the ordinary working capacity of each pump would be, say, 300 gallons per minute, to be increased to 450 in case of a sudden increase of water, or if an inundation should occur both pumps could be started, yielding a combined flow of 900 gallons, now it is evident that a steam pumping

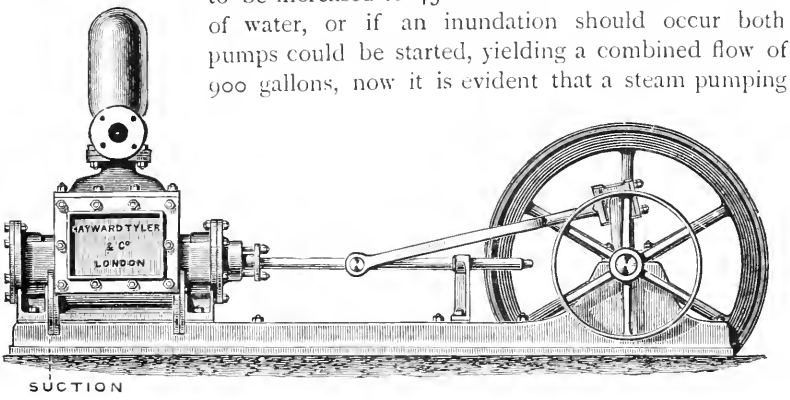


Fig. 105.—Elevation of the California Pump.

plant so arranged is less liable to flooding than is a Cornish plant, and by it work can be carried on uninterruptedly at the bottom level of the mine.

(*c*) The Cornish engine, with its ponderous rods, balance beams, angle beams, etc., is more liable to become deranged or to break in some of its numerous parts, than is the direct acting pump, while the irregularity in the motion of a Cornish engine causes sudden and heavy pressures, hammerings, etc., at high speeds, as a rigid mass of reciprocating rods are made to act on an equally rigid column of water at varying speeds; that is, starting from a state of rest up to a velocity of from 40 ft. to 80 ft. per minute, and again coming to a state of rest all of which cause sudden strains which sooner or latter end in breakage.

On the contrary, in the direct acting pump any irregularity in the water column is taken direct on the steam piston, the steam forming an elastic cushion, as it were, to receive all the shocks; while even if the water column of a high duty engine burst right at the pump, for example, the engine could not complete its stroke. On the other hand, should

the rods of a Cornish pump part, a new engine is usually required in order to make good the repairs.

The relative cost of the pumping plants varies considerably with the cost of freight, etc., but usually a duplex compound condensing, or even a high duty pump can be erected in duplicate and placed at work in a mine for from one-third to half the cost of a Cornish beam engine in working order.

Pumps for Mill Work.—It is not always possible to obtain a supply of clean water from a height which will feed it direct into a cistern at the top of the mill, and in these cases some kind of pump must be used to raise the water required for concentration purposes up to the height required to feed all the machines.

For this purpose there are a large variety of pumps in the market, such as those connected with the names of Tangye, Worthington, Hayward, Tyler, and many others, and of these a full description will be found in a work by Mr. Stephen Michell on "Mine Drainage." * It will be sufficient for our purpose, however, if I describe the pumps used in a mill erected by myself and which I found to work very satisfactorily. At first the only pump in use was one of the California type and of German make (fig. 104) driven by a belt and gearing; but this was of a defective construction and was constantly getting out of order, and with the enlargement of the mill was found insufficient to keep up the supply of water required in a large lead-dressing mill. A duplex pump was therefore ordered from the Pulsometer Engineering Company, of London, large enough to keep up the full supply of the mill if necessary, but the old California pump was also kept running at a slow speed, doing what it could, and as it was driven by water-power, it kept down the expense of the steam pumping of the duplex.

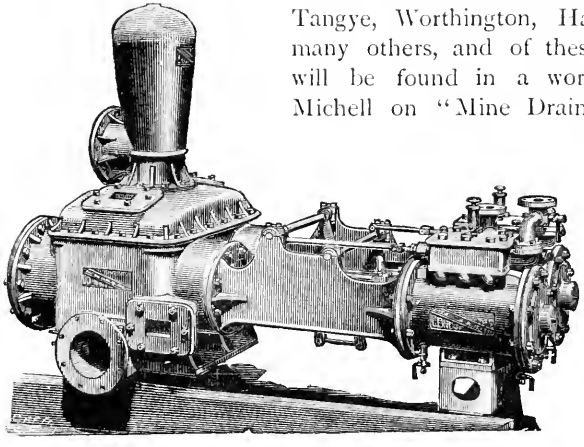


Fig. 106.—The Duplex Pump.

The duplex pump consists of two pumps and two cylinders placed side by side. The slide valves are of the well-known ordinary form.

* London: Crosby Lockwood & Son.

The action of the pump (fig. 106) is as follows: When the first pump is at the end of its stroke the piston rod of its fellow pump, by means of a swinging lever, actuates its slide valve, so as to give it steam at the other end of the cylinder, after which the second pump completes its own stroke and waits for the first pump, now in course of its stroke, to give steam in a similar manner. One of the steam valves is always open, so that there is no dead centre, and great steadiness and freedom from shocks is obtained by the use of the two double acting pumps, the water being delivered in a constant stream.

The pumps are of the internal plunger type, and the plungers are packed by removing the end cylinder covers. If asbestos packing is used it will be found to last for a long period without changing, though, if a knocking sound is heard inside the pump, it is a sign that the packing either requires renewal or the gland wants screwing up.

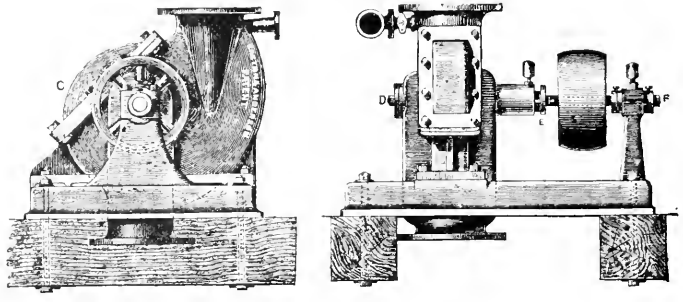
In places where fuel is scarce and expensive, the duplex pump is provided with an extra pair of cylinders, the pistons of which are operated by the exhaust from the cylinders to which the steam is first admitted. In other words, the pump is compounded and advantage taken of the expansion of the steam, and the economic effect of a cut-off is realised.

DUPLEX STEAM PUMPS, WITH INTERNAL PLUNGERS.—DIMENSIONS AND CAPACITIES OF A FEW SIZES.

Diameter of Steam Cylinder, in inches.	Diameter of Plungers, in inches.	Length of Stroke, in inches.	Capacity at 50 ft. Piston Speed per minute, in gallons per hour.	Capacity at 85 ft. Piston Speed per minute, in gallons per hour.	Size of Steam Pipe, in inches.	Size of Exhaust Pipe, in inches.	Size of Suction Pipe, in inches.	Size of Discharge Pipe, in inches.
6	4	10	3,200	5.440	1¼	1½	3	3
7½	4½	10	4.050	6.880	1½	2	3½	3½
7½	5¼	10	5.560	9.350	1½	2	4	4
9	5¼	10	5.500	9.350	2	2½	4	4
10	6	10	7.300	12.200	2	2½	4½	4½
11	6	10	7.300	12,200	2	2½	4½	4½
11	10	10	20.000	34,000	2	2½	7	7
11	10	15	20.000	34.000	2	2½	7	7
12	7	10	9.800	16,600	2½	3	5	5
12	8	10	12,800	21,700	2½	3	6	6
13	9	10	16.200	27,500	3	3½	7	7
14	7	10	91,800	16,600	3	3½	5	5
14	8	10	12,800	21.700	3	3½	6	6
14	10	10	20,000	34.000	3	3½	7	7
16	9	10	16.200	27.500	3	3½	7	7
16	10	10	20.000	34.000	3	3½	7	7
16	12	10	28,800	48,900	3	3½	8	8
16	14	18	39.200	66.400	3	3½	10	10
18	10	10	20,000	34,000	3½	4	7	7
18	12	10	28,800	48.900	3½	4	8	8
20	15	15	45,000	76,000	3½	4	12	12

Centrifugal Pumps.—The concentration of metalliferous ores is best effected where a continuous supply of fresh, clean water is available. It often happens, however, that the mill is so situated that the water is scarce and dear. In these cases the same water must be used over and over again after first passing through settling pits, in which the heaviest slimes are deposited. The water is, however, by no means clean, and those who have attempted the pumping of water charged with fine mineral matter, by means of ordinary pumps, can best appreciate the difficulties connected therewith.

A pump, therefore, which has practically no valves is especially valuable for milling purposes, and the centrifugal pump has been largely adopted where muddy waters have to be dealt with, as in the mills illustrated in figs. 302 to 307. This form of pump is not suitable, however, where the total lift is greater than from 50 ft. to 60 ft., and in no case should it



FIGS. 107, 108.—THE CENTRIFUGAL PUMP.

be placed at a greater height than 20 ft. above the surface of the water to be raised.

The ordinary form of the pump is shown in figs. 107 and 108, and, as will be seen, it can easily be erected upon a couple of baulks of timber for temporary, or on a masonry foundation for permanent work.

Great care must be taken that the joints of the suction pipes are perfectly air- and water-tight, and that the gland (E) round the pump spindle and the cover (D) does not leak.

The soundness of these joints is best tested by allowing the pump to stand a short time with the pipes full of water, when, if any leakage exists, it will probably show itself.

When the water to be raised is below the centre of the pump spindle, the pump must be charged before it can deliver any water.

This is done by filling the suction pipe and pump case full of water while the pump is at rest, to at least as many inches above the top of the fan, as there are feet of suction below it. For this purpose a tap and funnel are fixed into the pump casing, while the valve in

the straining box, at the foot of the suction pipe, prevents the escape of the water at the lower end.

The charging may also be effected by means of a steam ejector placed above the fan, but the former process is the more usual. As soon as the suction pipe is filled, the spindle is set in motion in the direction of the arrows cast on the case, and the water will begin to rise.

The sizes and power required for these pumps, as well as their approximate prices, are given in the following table. The speed varies, with the height of the lift, from 500 to 1000 revolutions per minute, and the duty is about 65 per cent. of the power expended.

Size of Pumps and Diameter of Pipes, in inches.	Gallons raised per Minute.—Maximum Quantity.	Diameter of Riggers by Width of Face, in inches.	Width of Belt in inches for 20-ft. Lift.	Kind of Belt.	Nominal Horse-power of Engine for 1-ft. high. —Maximum Quantity.	Pump complete, as figs. 1, 2, 3, 4, 5, and 6.			Pipes per foot, in 2-ft., 6-ft., or 9-ft. lengths, with Bolts and Joint Rings.		
						£	s.	d.	£	s.	d.
3	150	8 × 4	2	Single Bells.	0·045	12	0	0	0	2	3
4	260	9 × 4	2		0·078	13	0	0	0	2	10
5	400	9 × 5	2½		0·121	16	0	0	0	3	5
6	580	10 × 6	3		0·175	17	0	0	0	6	0
7	800	11 × 6	3½		0·242	17	10	0	0	7	0
8	1000	11 × 7½	4		0·303	18	10	0	0	7	3
10	1600	11 × 7	4	Double Bells.	0·484	24	0	0	0	8	6
12	2300	13 × 9½	5		0·7	35	0	0	0	11	0
13	2700	14 × 10½	6		0·818	40	0	0	0	12	3
16	4100	21 × 10½	7		1·242	67	0	0	0	15	0
18	5300	24 × 10	9		1·606	80	0	0	0	17	0
20	6500	30 × 11	10		1·97	95	0	0	0	19	0
24	9400	36 × 15	14		2·848	140	0	0	1	4	0

I have used centrifugal pumps for the purpose of lifting the "middlings" from a series of Lührig vanners, pumping them back to another set of vanners, as is shown in Plate XV. (page 458), and the description of the plant I erected for treating galena and blende at the Cwmystwith Mines. The pumps were placed in wells so that the level of the water to be pumped was always above the axle of the pump. The speed of the pump should be so adjusted as to take the quantity of slime waters as they arrive and without giving them time to settle, nor should it lift a greater quantity than that arriving, as in this case the well is emptied and the pump soon becomes choked with slime, owing to there not being a constant rush of water to carry off the thick mud.

Considering the rough work they are put to and the gritty nature of the stuff handled the wear and tear is not excessive. The interior is lined with hard steel plates which are renewed when worn from spare

parts kept in stock. The axle and the flier also wear and have to be renewed from time to time.

Pumping the Tailings from Batteries.—Very great difficulty has been experienced in pumping tailings, owing to the water necessarily being very gritty. The result has been the rapid destruction of both the buckets and valves of pumps usually employed.

These difficulties have been obviated by an arrangement of pump introduced by Hayward, Tyler & Co. The external appearance of the pump, as shown in fig. 109, does not differ materially from an ordinary double acting pump, but in place of the back cover is a long bonnet. In the interior of the pump, instead of a piston or bucket, there is a plunger working through a gland in the middle of the pump. This gland is easily accessible by removing the bonnet, and is packed with hemp and tallow. The plunger is found to work

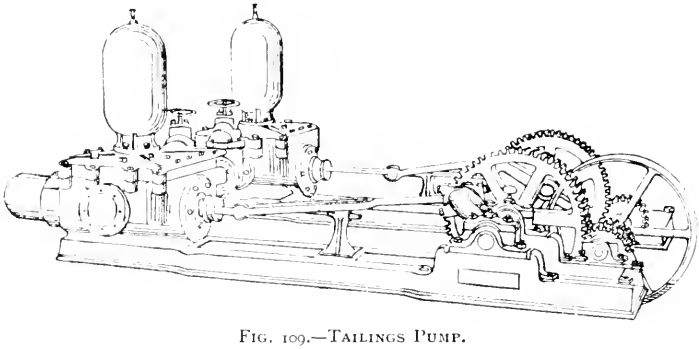


Fig. 109.—Tailings Pump.

very much longer than any form of piston, and it is much easier to repack the gland than to replace bucket leathers or rings. The valves of the pump are simply balls of solid mineralised rubber, which wear away without losing their efficiency for a very long period, and when worn too small can be replaced with the fingers, after removal of the cover. The seats are gun-metal cages, which appear to be practically indestructible, as the valve which works on them is of so much softer material. These pumps are made either singly or in pairs up to large sizes, and are being used in large numbers in the South African gold-fields.

Tailings Wheels.—Another device for lifting the mixture of sand and water known as tailings or slimes is by means of a tailings wheel such as that shown in fig. 110. This resembles a waterwheel except that the openings to the buckets are on the inside of the wheel. The tailings are led into these by means of a launder, lifted the height of

the wheel and emptied out into another launder which conveys them to the cyanide tanks or elsewhere.

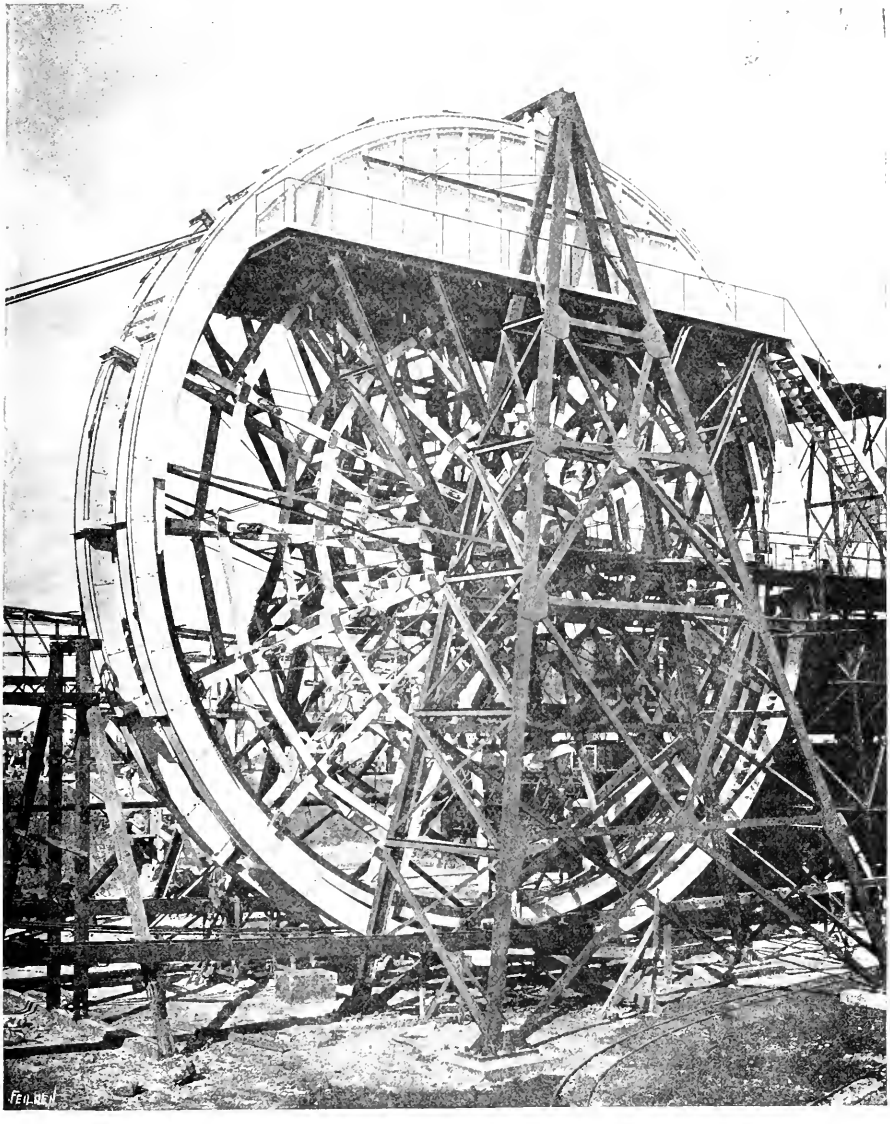


FIG. 110.—TAILINGS WHEEL.

The wheel in the illustration is driven by means of a cable working

on a V-grooved pulley fixed to the arms of the wheel. In other cases a toothed segment is used instead of the pulley, and a pinion driven from a belt pulley gears into this. I have had no experience with the cable method ; but with the pinion and segment, with which I am acquainted, the breakdowns are frequent and the wear and tear heavy. The speed of course is slow, say 4 revolutions per minute.

Memoranda and Rules relating to Water, the Power of Pumps, and the Capacity of Pumping Engines.

Weight and Measure of Water at the Common Temperature.

1 pint	= 34·65 cubic in., or 1·25 lb.
1 gallon	= 277·274 cubic in., or 10 lb.
11·2 gallons	= 1 cwt.
224 ,,	= 1 ton.
1 cubic inch	= 252·45 grains, or ·03617 lb.
12 ,, inches	= ·434 lb.
1 ,, foot	= 6·25 gallons, or 1000 oz., or 62·5 lb.
1·8 ,, ,,	= 1 cwt.
35·84 cubic feet	= 1 ton.
1 cylindrical inch	= ·02842 lb.
12 ,, inches	= ·341 lb.
1 ,, foot	= 5 gallons, or 49·1 lb.
2·282 ,, feet	= 1 cwt.
45·64 ,, ,,	= 1 ton.
1 cubic inch of mercury	= 3425·25 grains.
1 ,, foot of sea water	= 64·14 lb.
Weight of sea water	= weight of fresh water × 1·028.
Cubic foot of fresh water	= ·557 = cwt. approximate.
,, ,, ,	× ·028 = tons.

Useful Numbers for Pumps.

D = Diameter of pump in inches.
S = Stroke ,, ,,
$D^2 \times S \times .7854$ = cubic inches.
$D^2 \times S \times .002833$ = gallons.
$D^2 \times S \times .00045$ = cubic feet.
$D^2 \times S \times .02833$ = lb. fresh water.

Pressure of Water per Square Inch at Different Heads.

P = Pressure in lb. per square inch.
H = Head of water in feet.
$P = H \times .4333$. Roughly every foot of elevation = $\frac{1}{2}$ lb. pressure per square inch.
$H = P \times 2.31$.
Pressure per square foot = $H \times 62.4$.

To find the quantity of water which an engine will pump from a

given depth, multiply the horse-power by 550 and divide the product by the depth of the pit in fathoms; or—

Let H = Horse-power of engine.
,, F = Depth of pit in fathoms.
,, G = Quantity of water in gallons per minute.

Then $G = \frac{H \times 550}{F}$.
,, $F = \frac{H \times 550}{G}$.
,, $H = \frac{F \times G}{550}$.

Rule for calculating the quantity of water drawn at a single stroke in a working barrel of a given diameter: Square the diameter in inches, and divide by 10 for the gallons in a 3-ft stroke (see also page 102).

Rule for ascertaining the weight of water in pipes, reckoning 10 lb. to the gallon: Square the diameter in inches and the result will be pounds weight of water in a 3-ft. length.

Pumping Engines.—The data necessary for ascertaining the horse-power required to do a given amount of work in pumping, are simply the quantity to be raised in a given unit of time, and the height to which it is to be raised. The quantity is to be reduced to the weight in pounds raised per minute, and this weight is to be multiplied by the height in feet, and the product divided by 33,000, in order to find the horse-power required to perform the work in question. The standard which has been fixed upon to represent the work of one horse, is equal to 33,000 lb. raised through a space of 1 ft. high in a minute.

A gallon of distilled water at a temperature of 60° Fahr. weighs exactly 10 lb. avoirdupois; so that by adding a cipher to any quantity expressed in gallons, its weight in lbs. is obtained. Suppose for instance that it is required to find the horse-power capable of raising 350 gallons of water per minute to a height of 170 ft. Then 350 × 10 = 3500 lb. to be lifted per minute, and 3500 × 170 = 595,000 lifted one foot high per minute, and $\frac{595,000}{33,000} = 18$ horse-power.

When the quantity of water is expressed in gallons to be raised per 24 hours to a given height, it is necessary to divide this quantity by 1440, in order to find the quantity per minute; or, if the quantity in gallons to be raised to a given height per 24 hours is divided by 10 to bring it down to lbs., and then by 33,000 × 1440 = 47,520,000, the horse-power required to lift it is obtained direct. This may be represented by the formula which follows:

G = Number of gallons to be raised in 24 hours.
h = Height in feet to which it is to be raised.
H.P. = Horse-power required.

Then—

$$\text{H.P.} = \frac{G \times h}{4,752,000}.$$

To which, however, it is usual to add from 70 to 80 per cent. in order to allow for loss in friction and contingencies.

The area of the steam piston, multiplied by the steam pressure, gives the total amount of pressure that can be exerted. The area of the water piston, multiplied by the pressure of water per square inch, gives the resistance. A margin must be made between the power and the resistance to move the pistons at the required speed, say 20 to 40 per cent. according to speed and other conditions.

To find the capacity of a cylinder in gallons. Multiplying the area in inches by the length of stroke in inches will give the total number of cubic inches; divide this amount by 231 (which is the cubical contents of a United States gallon in inches) and product is the capacity in gallons. When divided by 277·27, the answer will be in Imperial or English gallons.

WEIGHT AND CAPACITY OF DIFFERENT STANDARD GALLONS OF WATER.

	Cubic Inches in a Gallon.	Weight of a Gallon in lb.	Gallons in a Cubic Foot	
Imperial or English . .	277·274	10·00	6·232102	Weight of cubic foot of water English standard. 62·321 lb. Avoirdupois.
United States	231·00	8·33111	7·480519	

A "miner's inch" of water is approximately equal to a supply of 12 United States gallons per minute, and varies from 1·36 to 1·73 cubic ft. per minute. (See also pages 23 to 27.)

Doubling the diameter of a pipe increases its capacity four times. Friction of liquids in pipes increases as the square of the velocity. (See table of "Friction of Water in Pipes," on page 28.)

The mean pressure of the atmosphere is usually estimated at 14·7 lb. per square inch, so that with a perfect vacuum it will sustain a column of mercury 29·9 in. or a column of water 33·9 ft. high.

A table showing the quantity of water in Imperial gallons, delivered by a pump at each stroke of the engine, will be found on page 101, in the chapter on the drainage of mines.

CHAPTER VII.

ROCK DRILLING MACHINERY.

Percussion Drills—Requirements of a Good Drill—Use of Steam—Compressors—Heating—Sources of Loss—Law of Volumes and Pressures—Variations in Atmospheric Pressure and Effect on Compressing Machinery Air Mains—Loss due to Friction—Air Leakage—The Schram Drill—The Sergeant Tappet Drill—The Ingersoll-Sergeant Auxiliary Valve Drill—The Optimus Compound Drill—Electric Rock Drills—Speed of Drilling—Cost of Drilling.

THE application of machinery to rock drilling has been in course of perfection during the past one hundred and fifty years, and, as is usual, the honour of being the original inventor is claimed by many men of various nations, while the subsidiary inventors and improvers have been still more numerous. We, however, have to consider the rock drill as it exists to-day, and to describe a few of the forms most frequently in use, without, however, asserting that they are the most perfect.

Rock drilling machines may be grouped into two great classes—first, those that bore by percussion combined with a comparatively slow rotation of the drill; and secondly, those that drill by constant pressure and rotation, of which the well-known Diamond drill described on page 201 is the best example.

The principle of the percussive drill is that of a steam cylinder, to the piston rod of which a boring tool is attached. The rapid strokes of the piston, which is usually driven by compressed air, though steam may be used, strike the boring bit against the rock, and so gradually cut a hole the same as in hand drilling.

The variations in the different patents and inventions consist of special arrangements by which the chief end is accomplished, as well as for turning the drill around as it works and in lengthening the machine, or so altering its position, as to adopt the blows to the ever-increasing depth of the hole.

The requirements of a good rock drill are stated concisely by André, in his work upon Coal Mining, as follows:

1. A machine rock drill should be simple in construction, and strong in every part.

2. It should consist of few parts, and especially of few moving parts.

3. It should be as light in weight as can be made consistent with the first condition.

4. It should occupy but little space.

5. The striking part should be relatively of great weight, and should strike the rock directly.

6. No other part than the piston should be exposed to violent shocks.

7. The piston should be capable of working with a variable length of stroke.

8. The sudden removal of the resistance should not be liable to cause any injury to any part.

9. The rotary motion of the drill should take place automatically.

10. The feed, if automatic, should be regulated by the advance of the piston as the cutting advances.

To which may be added that the best rock drill is equally strong in its recovery as in its blow—that is, it should have as much lifting power to get the bit out of a bad hole as it has force to drive it into a hole.

For quarrying purposes the drill is mounted upon a tripod, to the legs of which heavy weights are attached in order to give the necessary rigidity; and for these drills which are comparatively close to a boiler, steam is frequently used.

It can of course be also used for driving tunnels underground, but there are difficulties in the way of conducting it in the pipes without enormous loss from condensation, and also from the exhaust steam which must be condensed, or, otherwise, the tunnel would be too cloudy to work in, and which also does not contribute, as does the exhaust air, to the ventilation. The longest tunnel which has been driven by the use of steam for the drills is probably that known as the Magna Charta at Tomichi, Colorado, where the $1\frac{1}{4}$ in. steam pipes ran for 3000 ft. from the boiler to the drills in the face of the tunnel. As the work progressed the boiler pressure was gradually raised from 80 to 100 lb. per square inch, but after 3000 ft. an air compressor driven by water-power was put in, in the place of the steam and boiler.

Compressors.—Compressed air can be conveyed in pipes for several miles, and still be capable of performing very useful if not economical work. As a means for the transmission of power, whether to rock-drills, pumps, or hauling-engines, it possesses defects of a serious character; and these arise from various causes, one of the principal of which is the heat accumulated during the act of compression. The reason for the resulting loss will be readily understood when we

know that heat acts expansively upon air; in other words, a volume of air will exert less pressure upon the sides of a containing vessel when at a temperature of 10° than when at 20°.

This being true, the piston of a compressing engine is met both by the natural resistance of the air to compression and by the increased resistance due to the expansion by heat. To illustrate this, suppose we have one cubic foot of air at atmospheric pressure, and at a temperature of 60°, and then compress this air to 58·8 lb. per square inch, the volume of the air will be reduced to ·3194 of a cubic foot, and its temperature will have risen to 369·4°, making an increase of 309·4°.

The all importance of supplying the compressor with air at as cold a temperature as possible, from outside the engine-room, and of keeping the compressing cylinder cool by means of a constant stream of cold water circulating through the water jacket, is very evident from the above example. In some machines a spray of cold water is injected into the cylinder in order to cool the air more rapidly, but this system is not to be recommended, both because it rusts the inside of the cylinder, and also because it moistens the air, which, on expansion, when leaving the exhaust ports of the drills, freezes and clogs the machine with ice.

Compressed air occupies considerably less volume than free or atmospheric air, and, in this particular, follows Mariotte's law, which is that the pressure of any gas varies in the inverse ratio to its volume, the temperature remaining constant, so that if

P = the original pressure.
P' = .. new ,,
V = ,, original volume.
V' = ,, new ,,

$$P' : P = V : V'.$$

Example.—What vol. V' will 100 cubic ft. of atmospheric air (which at the sea level averages about 15 lb. per square inch) occupy, when compressed to 60 lb., or 4 atmospheres, effective pressure (5 atmospheres, absolute)?

$$V' = \frac{P \times V}{P'}$$

$$= \frac{15 \times 100}{60 + 15} = 20 \text{ cubic ft., or one-fifth of original volume.}$$

So that approximately the volume of compressed air is equal to the original volume, divided by the number of atmospheres (absolute) to which it has been compressed.

Example.—Required the size of compressor to supply air at 60 lb., effective pressure, to work two 3-in. drills.

Air required per minute—

$$15 \times 2 = 30 \text{ cubic ft. at 60 lb.,}$$
$$\text{or } 30 \times 5 = 150 \text{ ,, of free air at}$$

atmospheric pressure would be required per minute to work both drills simultaneously.

Taking the piston speed at 300 ft. per minute—

$$\text{Area of cylinder} \times 300 = 150$$
$$\text{,, ,,} = \tfrac{150}{300} \text{ sq. ft.} = 72 \text{ sq. in.}$$

which represents a cylinder diameter of $9\frac{1}{8}$ in. to which the nearest sized compressor would be 10 in. diameter.

A smaller plant than a 10-in. compressor and two drills is very seldom employed, and would not be economical.

Example.—Required the size of compressor to supply air at 60 lb. effective pressure to work six $3\frac{1}{2}$-in. drills.

Air required per minute—

$$20 \times 6 = 120 \text{ cubic ft. at 60 lb. pressure,}$$
$$\text{or } 120 \times 5 = 600 \text{ ,, of free air at atmospheric pressure.}$$

Assuming a piston speed of 350 ft. per minute—

$$\text{Area of cylinder } 350 = 600 \times$$
$$\text{,, ,,} = \tfrac{600}{350} \text{ sq. ft.} = 247 \text{ sq. in.}$$

which represents a cylinder of $17\frac{3}{4}$ in. diameter, the nearest sized compressor to which would be an 18-in.

It would be possible to drive the 6 drills with a 16-in. compressor running a little faster, taking into consideration that seldom more than 5 drills would be working at one time; on the other hand, it would be more economical, and better, in the long run to employ an 18-in. compressor.

A rule by which the volumes of compressed air may be approximately determined from volumes of free air, is to divide by the number of atmospheres. For instance, 60 lb. represent five atmospheres (absolute—that is, taking the atmospheric pressure of 15 lb. into account), 500 cubic ft. of free air divided by 5 = 100 cubic ft. of compressed air, at 60 lb. gauge pressure. This rule gives only approximate results, as the pressure is not always an exact multiple of an atmosphere.

Another most important point which has very considerable practical importance, is that the above rules are based upon the data of sea level, at which the normal atmospheric pressure is 15 lb. per square inch. Most mines, however, are in elevated regions; the atmospheric pressure,

therefore, is less, as shown in the following table in colume A. In column B will be found the difference in volume, as compared with the volume of air at the sea level, which is taken as being 1.

		A	B
Pressure at	¼ mile above sea level	14·02 lb. per sq. in.	7% less.
,,	½ ,, ,,	13·33 ,, ,,	11% ,,
,,	¾ ,, ,,	12·66 ,, ,,	16% ,,
,,	1 ,, ,,	12·02 ,, ,,	20% ,,
,,	1¼ ,, ,,	11·42 ,, ,,	24% ,,
,,	1½ ,, ,,	10·88 ,, ,,	28% ,,
,,	2 ,, ,,	9·88 ,, ,,	34% ,,

In practice, approximate determinations of the reduced efficiency of air compressors are made by deducting the percentage of difference between the barometric pressures at the respective altitudes, or by the following rule: Assuming efficiency at sea level to be 100, then the decrease of efficiency for every 1000 ft. of altitude is approximately 3 per cent.

Another practical difficulty which involves loss of efficiency in the compressor, is due to the clearance space at the ends of the cylinder which, at the completion of a stroke, is full of compressed air. Now, before the forward stroke can draw in a new supply of air from outside, this cushion of compressed air must lose its pressure by expansion, so reducing the quantity of fresh air, which can be drawn in and compressed. Add to this the leakage of the pressure valves, which allow a certain quantity of compressed air to slip back into the cylinder from the air receiver, and we see at once how great a percentage must be deducted for loss from the theoretical quantity of air which the machine should compress, and which varies, according to the make of the compressor, from 5 to 10 per cent.

Air Mains.—In designing a rock drill plant the greatest care should be taken to make the air pipes of ample size, so as to allow a free passage to the air, which travels within them at a velocity of from 25 to 30 ft. per second. All unnecessary angles and bends should be avoided, as they add greatly to the friction of the air, and consequently decrease the pressure, which is proportional to the length of the pipe and the square of the velocity.

For pipes up to and including 5 in. diameter, wrought iron or steel is usually employed, with ordinary screwed sleeve connections. The larger sizes are supplied with flanges, the joints being made with gaskets or indiarubber rings. Pipes with flanged joints are more convenient for use in shafts where the screwing of sleeve-jointed pipes is a source of trouble and delay.

The smaller pipes up to 1¼ in. diameter are tested to a pressure of 300 lb. per square inch, while the larger are tested to 500 lb. per

square inch. Great care must be taken that the joints are perfectly air-tight, as the amount of loss even from a pinhole is very considerable.

The following table will show the loss in air pressure due to friction in the pipes, and is calculated for each 1000 ft. of pipe line. For other lengths of pipe the loss is in direct proportion:

INSIDE DIAMETER OF PIPE IN INCHES.

Velocity in ft. per Second.	1-in.		2-in.		3-in.	
	Cubic ft. of Free Air per Minute. Pressure 60 lb.	Loss of Pressure in lb. per square in.	Cubic ft. of Free Air per Minute. Pressure 60 lb.	Loss of Pressure in lb per square in.	Cubic ft. of Free Air per Minute. Pressure. 60 lb.	Loss of Pressure in lb. per square in.
3·28	6	0·143	23	·079	48	·046
6·56	12	0·640	46	·305	96	·212
9·84	18	1·450	69	·721	144	·488
13·12	24	2·560	93	1·256	193	·838
16·40	29	3·930	116	1·964	241	1·317
19·68	35	5·420	139	2·712	289	1·807
26·24	47	10·240	185	5·026	386	3·351
32·80	59	15·730	232	7·856	480	5·270
	4-in.		5-in.		6-in.	
3·28	86	·035	134	·028	193	·023
6·56	172	·152	268	·153	386	·104
9·84	258	·361	402	·290	579	·244
13·12	343	·628	537	·512	772	·419
16·40	429	·981	671	·786	965	·659
19·68	515	1·355	805	1·084	1158	·904
26·24	687	2·512	1073	2·049	1544	1·675
32·80	859	3·927	1342	3·146	1931	2·634

Example.—An air compressor furnishes 386 cubic ft. of free air per minute at a pressure of 60 lb. per square inch in the receiver. If this air is used at the end of a 3-in. pipe 1000 ft. long, the loss due to friction will be $3\frac{351}{1000}$ lb. If the same volume of air were supplied by the same compressor at the same pressure and passed through a 6-in. pipe 1000 ft. long, the loss would be only $\frac{104}{1000}$ lb.; thus illustrating the importance of using pipe of large diameter. If the pipe were 500 ft. long the loss would be one-half as much; if 2000 ft., it would be double as much, and so on for any length.

Elbows and irregularities in pipe increase the friction above the figures given in the table.

The foregoing table represents only the loss by friction in the pipe. There is a further slight loss due to the friction of the air with itself at the mouth of the pipe when it leaves the receiver.

Air Leakage.—All leaks in compressors or valves, air receivers or pipe, should be strictly guarded against for the sake of economy in the running of compressed air and steam apparatus. Air leaks are fully as expensive as steam leaks, and should be as carefully stopped. Too many miners think that an air leak is of but little consequence, but in reality it should never be allowed, save where needed for actual ventilation. When it is remembered that air issues from a leaky joint in a pipe at a velocity of over 500 ft. per second, at 60 lb. pressure, the waste of power from leakage will become apparent.

The pipes on the surface may be either buried or laid on the ground; in the mine they are usually supported on the timbers. When the pipe line crosses deep gullies, the pipes may be slung from a cable by means of hooks, but in this case especial care should be taken with the joints as once the pipes are slung a leak cannot be detected. The spaces may be anything up to 100 yds., but should of course be as short as possible. Care should be taken when laying the pipes to prevent the entrance of sand or gravel as this would finally find its way into the drills and cause damage.

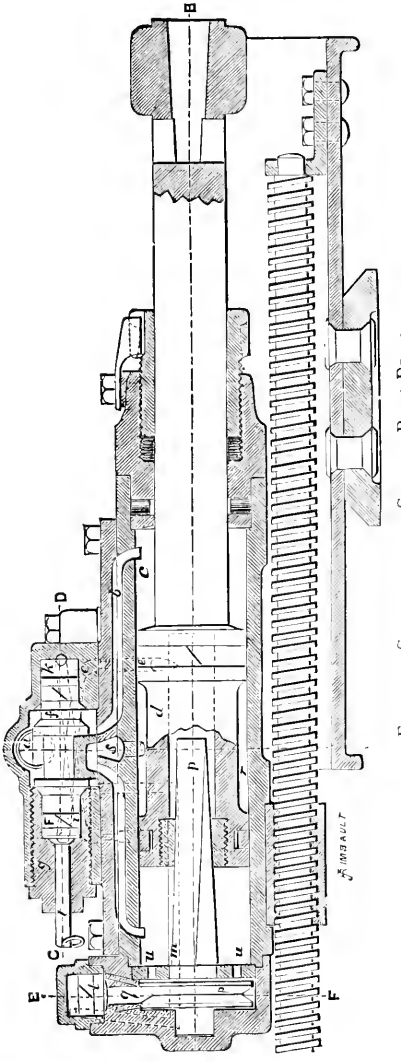


FIG. 111.—SECTION OF THE SCHRAM ROCK DRILL.

The Schram Rock Drill.—The mechanism of the Schram rock drill is shown in fig. 111, and is typical of those drills in which the motion of the slide valve is controlled by the main piston without the intervention of tappets.

Referring to fig. 111, *i* is the main piston, *i i* the slide valve piston

and slide, *i i i* the rotating movement with its piston. In the newer forms of the machines, however, the rotating movement is regulated by a ratchet and pawl instead of the arrangement here illustrated.

The working of the machine is as follows:—When the piston (*d*) is in the position shown, and on cock being opened the air or steam enters the cylinder (*c*) through the port (*b*) and, pressing on the lower end of the piston (*d*), forces it backward, causing the backward stroke. As soon as the piston (*d*) has passed the port (*e*) air rushes through that port into the small cylinder (*g*) in the slide box. At this moment, when the air presses upon the upper end of the slide piston (*f*) the cylinder (*k*) is in communication with the outlet (*s*) through the port (*i*) and the circular hollow in the piston rod (*r*); consequently, the slide piston with the shell is moved downwards, so that the passage (*h*) is opened for the admission of air from the slide box, whilst the lower end of the cylinder through the port (*l*) now communicates with the outlet (*s*). The air now entering (*c'*) through the opened port (*h*) presses on the upper end of the piston, forcing it forward, and thus causing the drill, carried in a socket at the extremity of the piston rod, to strike with the impetus of its own weight and all the power of the compressed air against the rock. As soon as the piston (*d*) has passed the port (*i*) air enters through it into the cylinder (*k*). At this moment the cylinder (*g*) communicates with the outlet (*s*) through the port (*e*) and the circular hollow (*r*) in the piston rod, and the side piston with the slide is moved back into the same position. Meanwhile the piston (*d*) has completed its stroke; the cylinder (*c'*) is through the passage (*h*) in communication with the outlet (*s*); and the compressed air again rushing through the re-opened passage (*b*) causes the action just described to be repeated so long as the supply of motive power is kept up.

It is an important feature of this machine that the slide rod (*f*) is made in the form of a double spindle valve. By this method of construction it remains in position, without any recoil, until the piston (*d*) has made the greater part of its stroke.

As, in some varieties of rock, it happens that the drill often sticks fast, there is a reversing rod (*t*) to suddenly reverse the slide and pull the drill out of the hole. With careless workmen it would frequently happen that the piston would strike against the lower cylinder cover; therefore an air cushion is placed at the lower end of the cylinder. In addition, there is an iron ring and an india-rubber washer (exchanged for one of wrought iron when steam is used), with the object of moderating the violence of the shock which such blows, inadvertently permitted, would cause.

In order that the hole drilled may be perfectly round, it is necessary that the cutting tool should partially rotate at each backward stroke, so that its cutting edge shall every time strike the rock in a fresh place;

but in order to avoid loss of power it must make its forward stroke without rotating.

For this purpose a twisted bar (*o*) is employed, connected in the new drills with a ratchet wheel at *p*, which is free to rotate in one direction, but is held by a pawl engaging in its teeth, and so prevented from turning in the opposite. When the piston makes its forward stroke the ratchet allows the twisted bar and ratchet wheel to make a partial rotation; but on the return stroke the pawl retains the ratchet wheel, and the piston is bound to work in the grooves of the twisted bar, and so give itself a slight twist round, causing the bit to strike in a new place on the next forward stroke.

This drill has acquired a large reputation, and the latest use to which it has been put is the drilling of the holes in the rocks which protruded through the bottom of H.M.S. *Howe*, sunk in Ferrol harbour, previous to their being removed by blasting.

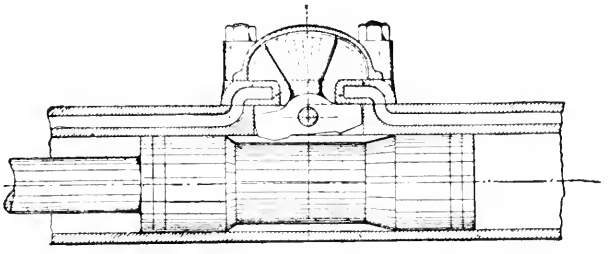


Fig. 112.—Sergeant-Tappet Valve.

The Sergeant-Tappet Drill.—In all the earlier rock drills the slide valve was moved by mechanical means, and received the name of tappet drills. It is unnecessary to illustrate all the devices which have been conceived for this purpose; it will be sufficient, I think, to illustrate the most improved and simplest form of tappet motion as used in the Sergeant-tappet drills in quarry work, where the steam is wet and the rock reasonably soft. The drill will work anywhere with steam or air, but for work in hard rock the Ingersoll-Sergeant drill, with an independent valve, as described on page 164, is said to be more efficient and more economical.

The arrangement of the tappet valve is shown in fig. 112. The fan-shaped valve and the rocking bar are all in one piece, and the movement is effected by the inclined planes of the piston coming in contact with the end of the rocking bar, and so alternately reversing the position of the slide valve, which opens and closes the pressure and exhaust ports in conformity with the stroke of the piston.

The pressure of the air or steam keeps the valve constantly against

the face, and, as it is made of the best materials, the wear and tear are reduced to a minimum.

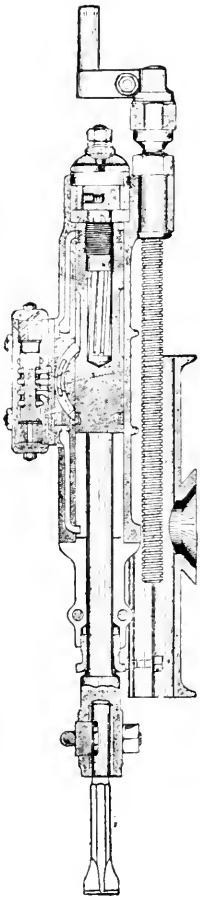


FIG. 113.—THE INGERSOLL-SERGEANT AUXILIARY VALVE DRILL.

The various drills manufactured by the Ingersoll-Sergeant Drill Company—from the "Old Reliable Eclipse" down to the latest Auxiliary valve drill—have been before the mining public for so many years and in such large numbers (there are, I believe, over 10,000 in use), that most mining men have come into either theoretical or practical contact with them. I have, therefore, confined my description to the newer and less-known types, which embody all the modern improvements.

The Ingersoll-Sergeant Auxiliary Valve Drill.—The special feature of the Ingersoll-Sergeant drill, as now made, is that the main valve is operated through an auxiliary valve, this latter receiving its motion from the piston and acting, so to speak, as a trigger to the main valve.

The arrangement will be understood by reference to the section of the drill given in fig. 113. The auxiliary valve is made of light steel in the form of an arc of a circle, and in consequence is easily moved by the piston at the end of its stroke. The subsidiary thus act as a slide valve to the main valve, which is moved by the air pressure in accordance with it, and so in its turn regulates the supply of air to the main piston.

The drill strikes an uncushioned blow. The main slide valve is held in such a position by the action of the auxiliary that, while the piston carrying the cutting tool is moved towards the rock, the full pressure of air or steam acts upon it until the blow is struck, at which moment the valve immediately reverses it.

The full pressure thus being kept up until the last moment, the air is not used expansively, and as the backward stroke is an equivalent of the forward, the power of the machine to withdraw the drill from tight or crooked holes is exactly equal to its power of striking a blow; and there is consequently less tendency to get jammed.

In order to avoid breakage from careless feeding, resulting in the piston striking either the front or back end of the cylinder, two strong

steel springs are used as buffers. These springs are placed on the back head, and are connected with the front head through side bolts, in such a manner that a blow either on the front or back heads is cushioned by the springs and a breakage prevented.

The feeding of the Ingersoll-Sergeant drills, and, indeed, of all drills used in mining or tunnelling, is now effected by hand; but for surface work with large drills making vertical holes an automatic feed attachment is of great value, especially in countries where skilled men for running the drills are scarce, and one man has to look after several machines. These drills, however, are not within the scope of mining proper, and so do not demand a detailed description.

The Optimus Compound Rock Drill.—There are many reasons which prevent the ordinary rock drill from being worked with the same economy of steam or air as is effected in a high-glass engine. As a

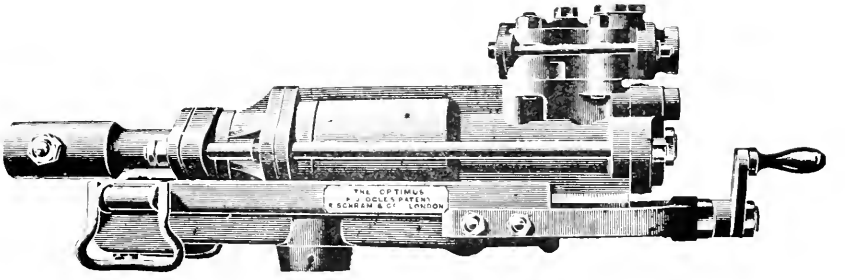


FIG. 114.—THE OPTIMUS COMPOUND ROCK DRILL

rule, the waste of air is very considerable, varying, of course, according to the numerous devices of different makers for controlling its admission to, and exhaust from, the cylinder. In the Optimus drill, manufactured by Messrs. Schram and Co., the compound principle has been brought into play, and is said to effect a saving of 45 per cent. of air less than that of any other drill of the same size.

A general view of the machine will be seen in fig. 114, and a section in fig. 115. The lower end of the cylinder is bored out to a larger diameter than the upper, and the air under pressure used for the forward stroke instead of being exhausted into the atmosphere in the usual manner is conducted to the front end of the cylinder, and, acting upon the increased area of the piston, is utilised for the backward stroke, thus effecting the above-mentioned saving.

This economy in air used at the drill reacts over the whole plant, and permits of smaller-sized compressors, boilers, and piping being used.

Referring now to the sectional drawing (fig. 115), the operation of the machine is as follows: Assuming the piston and valve (*e*) to be in

the position shown in the illustration, the cylinder (*a*) will be in communication with the atmosphere through the ports (*m*, *f*, and *h*). The result of this will be that the piston is forced forward, and, immediately the piston (*c*) uncovers the small port (*d*), a portion of the compressed air passes into the small cylinder (*r*) behind the valve (*e*); and acting on a larger area than that which is subject to the constant pressure at *l*, and the fact that there is no resistance at the other end of the valve (*e*) owing to the passage (*n*) communicating with the atmosphere, forces the valve (*e*) over to the other end of the valve chest, thereby cutting off the communication with the air under pressure, and placing the cylinders (*a* and *a'*) in communication through the ports (*b* and *m*). Then the air that has acted on the piston (*c*) now passes into the cylinder (*a'*) where it acts on the piston (*g*) of larger area than the piston (*c*) thereby moving the piston backwards to its original position. When the

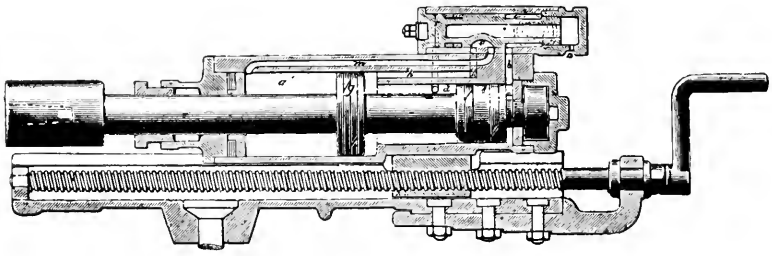


FIG. 115.—SECTION OF THE OPTIMUS COMPOUND ROCK DRILL.

piston (*c*) during its backward stroke passes the port (*d*) the cylinder (*r*) is placed in communication with the atmosphere through the ports (*d* and *h*) and the constant pressure acting on the piston valve (*e*) at *l* moves the said valve over to the position as shown in the illustration, the air again enters the cylinder (*a*) and the action is repeated.

It will be seen that the air used for the forward stroke is again utilised for the backward stroke without in any way impeding the piston in its forward stroke, and this, as well as the shortness of the port (*b*), causes a great saving of motive fluid. The air being instantaneously admitted to the cylinder (*d*) while the cylinder (*a'*) is in free communication with the outlet, causes the piston to give a very powerful blow, which makes this machine more effective than any other rock drill using considerably more motive power. At the end of each backward stroke there is still some pressure left behind the piston (*c*) which fact has three distinct advantages, viz.:

(1) It assists in cushioning the piston at each backward stroke, thus a smaller space for an air cushion is required.

(2) The presence of this air pressure causes the space in the cylinder

to be more quickly filled up with air at full pressure, which will give to the piston a more powerful blow.

(3) It causes a saving in motive fluid.

As a comparison with the weight and price of the ordinary machines, it may be stated that a 3-in. diameter Optimus with its cradle weighs 220 lb., and costs £52. A $3\frac{1}{4}$-in. diameter weighs 255 lb., and a $3\frac{1}{2}$-in. 310 lb., and cost £55 and £60 respectively. The makers claim that whatever can be done with ordinary drills can be done equally well with these compound ones, and that the saving effected in air is at least 45 per cent.

On the other hand it is argued that as a rock drill can never work continuously, and that for at least two-thirds of its time it is lying idle during the operation of starting and removal from one point to another, the saving of air effected by compounding can be but slight. It seems to us, however, that slight as this saving may be, it is of real value where a large number of drills are in operation, and especially when steam is employed to drive the compressor.

My own experience of these drills has been very satisfactory, and there is undoubtedly a saving in the air consumption. This I proved when using a small air compressor which, working through some two miles of 3-in. pipe, would only drive one drill of another make, but would drive two of the compound drills of which I now have sixteen at work.

The drill in most general use for mining purposes has a cylinder of 3 in. diameter.

The Tuckingmill Foundry Company, of Camborne, Cornwall, manufacture a drill known as the "Little Hercules" of which I hear excellent reports. They also make a stoping drill called the "Baby" drill which, as its name implies, is small, handy, and easily carried about even in difficult stopes.

Electric Rock Drills.—Many attempts have been made to use electricity as a motive power for driving drills direct without the intervention of a compressor; but, as applied to percussion drills, they have not as yet been a marked success. For diamond drills electricity, as will be seen later on page 211, has a fair field open, but even here for underground work not only the question of insulation in damp levels, but that of ventilation also demands serious consideration. I have seen electric percussion drills experimentally tried, both those of the solenoid type and those driven from a detached motor through a flexible shaft; but, as far as I am aware, they have not as yet entered into practical use on an extensive scale in mining.

Speed of Drilling.—The rate at which a tunnel can be driven by means of rock drills may be safely taken at double the speed of handwork.

I find from the records of the progress made in driving the heading (8 ft. × 20 ft.) of the Vosburg tunnel on the Lehigh Valley Railway, through a uniform hard grey sandstone, that by hand drilling the average progress was 67 ft., while that of the machine drilling was 173 ft. per month. There can be no question that, for driving and sinking, machine drills are far superior to hand labour both in speed and economy. For stoping, however, except in wide stopes, the difference between the two systems is not so marked, as it is difficult to manœuvre a machine in places where a man can hardly find room to work with a single hand hammer.

Cost of Drilling.—The great advantage in the use of rock drills is undoubtedly the increased speed with which a mine can be developed and reserves of ore created; from the question of cost per yard they are much on a par with hand drilling. The point is a little difficult to decide, but it would be safe to say that the average cost per yard by either system is the same as far as mining in small tunnels is concerned. The question of large tunnels, such as railway tunnels, need not be considered here, nor the use of special carriages for the support of two or more drills working at the same time, as the usual run of mining operations is on a much smaller scale.

CHAPTER VIII.

ROCK DRILLING MACHINERY (continued).

Air Compressors—Compressing Plant—The Pierrefitte Air Compressor Installation—The Cwmystwith Air Compressing Plant—The Riedler Compressor—Compound Air Cylinders and Double Stage Compressing—Supporting Columns and Tripods for Drills—Steel Bits and Sharpening Tools—The Working of Rock Drills—Specification of a Rock Drilling Plant.

Air Compressors.—The machines for compressing air are now built especially for that purpose, and may be driven indirectly by the power of water, electricity, or steam through the intervention of belting or

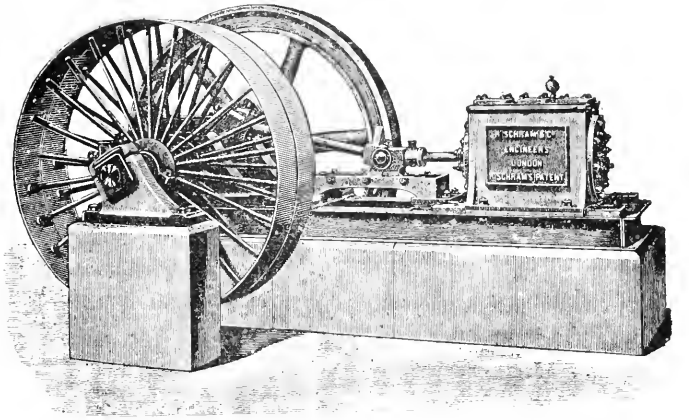


Fig. 116.—Schram's Air Compressor Driven by Belting.

gearing, or directly by steam, in which case the air compressing and the steam cylinders are usually fixed in one line, tandem fashion, with a piston rod common to both.

Of the former type fig. 116 is an illustration, and may be driven by a belt from a portable engine, or from a line of shafting, or by gearing from any motor, a fast running being preferable to a slow one.

These compressors can be procured in sizes varying by each 2-in. diameter of cylinder, from one of 8-in. diameter and 16-in. stroke, weighing complete 28 cwt., up to a 22-in. diameter and 30-in. stroke,

Diameter Air Cylinder.	Stroke in Inches.	No. of Revolutions.	Piston Speed in Feet per Minute.	Cubic Feet Free Air per Minute.	No. of 3-in. Drills or Coal Cutters.	Weight of Heaviest Piece.	Size of Pulley.	Complete Weight with Pulley.	Size of Pulley with Gears.	Weight with Pulley and Gears.	Horse-power required.	Approximate Price.	
												Belt.	Geared.
Inches.						lb.	ft. in.		ft. in.			£	£
8½	12	160	320	117	1	975	4 × 5	3500	...	...	15	160	...
10½	12	160	320	183	2	975	5 × 6	4500	...	...	30	190	...
12½	14	155	361	295	3	1650	6 × 8	5600	...	...	40	255	...
14½	18	120	360	398	5	2900	8 × 9	9400	6 × 9	13100	55	330	400
16½	18	120	360	518	7	2900	8 × 12	11000	6 × 12	14500	70	400	450
18½	24	94	376	683	10	4950	10 × 16	17000	10 × 12	19000	100	...	550
20½	24	94	376	840	12	4950	10 × 20	19000	10 × 16	20400	130	...	620
22½	30	75	375	1011	16	7000	12 × 22	22000	10 × 20	25300	155	...	790
24½	30	75	375	1201	20	7000	14 × 24	24000	12 × 20	30500	200	...	970

weighing 12 tons. Where large quantities of air are desired it is better to have two or more small cylinders in preference to one large one, in order that the strain on the shaft may be more equally distributed.

The larger sizes are for supplying air to underground engines or pumps, or to a large number of drills.

It sometimes happens that there is a spare engine lying in stock at the mine. In this case, if it is a horizontal one with a heavy flywheel, the bed plate and piston rod can be lengthened, and a compressing cylinder added behind the steam.

In the smaller-sized compressors the crank shaft is driven direct by means of a pulley and belt, but with the larger ones a set of gearing is supplied in addition. The adjoining table will give the general dimensions and capacities of compressors of this class, with varying diameter of cylinders.

The use of electricity for driving this class of compressor is described on page 173, and with the Pelton waterwheel on page 18, both these systems having been used by me most successfully.

It is not, however, always possible to attach the compressor to some already existing source of power, or to drive it by means of water or electricity; and in this case either a temporary or permanent steam plant is set up, consisting of a boiler, engine with compressor, and an air receiver; this latter being, of course, necessary under all circumstances, in order to ensure a steady working pressure and a uniform velocity of air.

Such a plant is usually arranged, as shown in figs. 116A and 116B, though, if steam can be spared from any existing boiler, it is, of course, unnecessary to erect a special one. The compressor (A) is bolted down to a solid foundation, and is one of the Ingersoll-Sergeant piston, inlet, cold-air, class A type. The steam cylinder (1) is connected direct to

FIG. 116A.

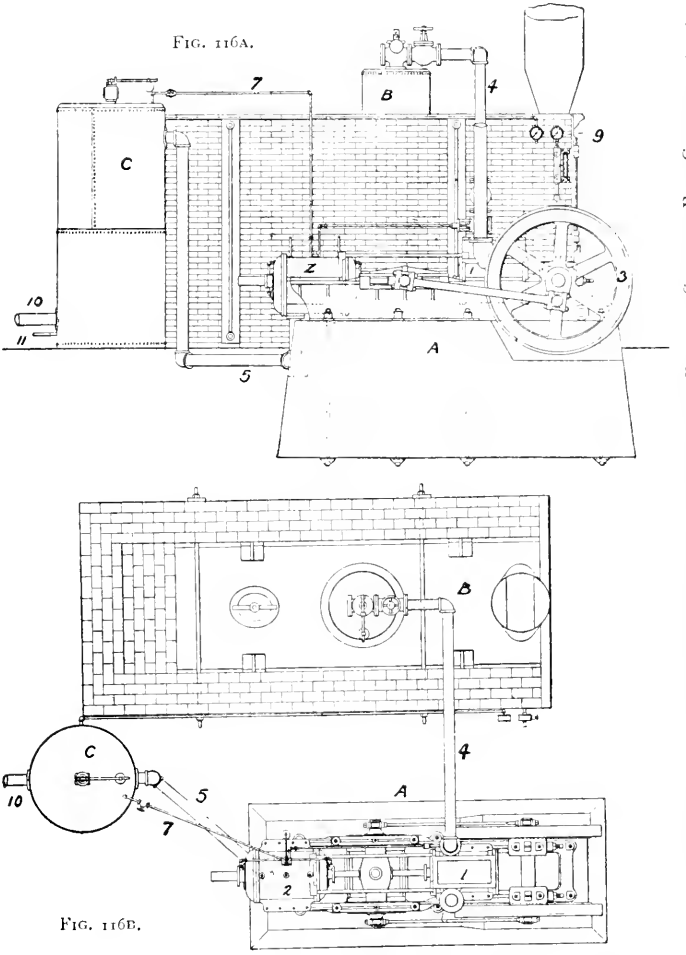


FIG. 116B.

PLAN AND ELEVATION OF AIR COMPRESSOR, AIR RECEIVER, AND BOILER, SHOWING PIPE CONNECTIONS AND AUTOMATIC AND ADJUSTABLE REGULATOR, AND UNLOADING DEVICE FOR AIR AND STEAM.

the air cylinder (2) and the speed is regulated by the heavy flywheels (3), the whole being solidly built on a cast iron bed plate. The air is drawn through the hollow extension of the piston rods, from which this compressor takes its name, and is discharged through the pipe (5) into the receiver (C). The steam arrives from the boiler (B) through the pipe (4) and is exhausted through the pipe (6).

TABLE GIVING SOME OF THE MOST IMPORTANT DIMENSIONS OF THE COMPRESSING PLANT SHOWN IN FIGS. 116A–116B.

DESIGNATION.	SIZES.						
Size of steam cylinder	10 × 12 in.	12 × 14 in.	14 × 18 in.	16 × 18 in.	18 × 24 in.	20 × 24 in.	22 × 30 in. 24 × 30 in.
Size of air cylinder	$10\frac{1}{4}$ × 12 in.	$12\frac{1}{4}$ × 14 in.	$14\frac{1}{4}$ × 18 in.	$16\frac{1}{4}$ × 18 in.	$18\frac{1}{4}$ × 24 in.	$20\frac{1}{4}$ × 24 in.	$22\frac{1}{4}$ × 30 in. $24\frac{1}{4}$ × 30 in.
Size of steam pipe	$2\frac{1}{2}$ in.	3 in.	$3\frac{1}{2}$ in.	4 in.	5 in.	5 in.	5 in. 6 in.
Size of exhaust pipe	3 in.	4 in.	4 in.	5 in.	5 in.	6 in.	6 in. 7 in.
Size of air pipe	3 in.	$3\frac{1}{2}$ in.	$3\frac{1}{2}$ in.	4 in.	5 in.	5 in.	5 in. 6 in.
Size of water circulating pipe	$\frac{3}{4}$ in.	$\frac{1}{1}$ in.	$\frac{3}{4}$ in.	$\frac{3}{4}$ in.	1 in.	1 in.	1 in. 1 in.
Size of drip pipes	$\frac{1}{2}$ in.	$\frac{5}{8}$ in.	$\frac{3}{4}$ in.	1 in.	$\frac{3}{4}$ in.	$\frac{3}{4}$ in.	1 in. 1 in.
Number of revolutions per minute	160	155	120	120	94	94	75 75
Indicated horse-power of boiler	30	40	55	70	100	130	155 200
Weight of heaviest piece (bed-frame)	975 lb.	1,650 lb.	2,900 lb.	2,900 lb.	4,950 lb.	4,950 lb.	7,000 lb. 7,000 lb.
Weight of flywheels on shaft	1,050 lb.	2,550 lb.	3,125 lb.	3,700 lb.	6,100 lb.	7,200 lb.	8,500 lb. 10,500 lb.
Weight of complete compressor	5,500 lb.	7,400 lb.	10,800 lb.	12,000 lb.	20,050 lb.	21,400 lb.	29,000 lb. 34,500 lb.
Length over all	10 ft. 10 in.	11 ft. 3 in.	13 ft. 9 in.	14 ft. 0 in.	16 ft. 10 in.	17 ft. 2 in.	20 ft. 6 in. 20 ft. 6 in.
Length of bed plate	8 ft. 0 in.	9 ft. 7 in.	11 ft. 9 in.	11 ft. 9 in.	14 ft. 7 in.	14 ft. 7 in.	17 ft. 2 in. 17 ft. 2 in
Width over all	2 ft. 10 in.	3 ft. 7 in.	4 ft. 1 in.	4 ft. 2 in.	5 ft. 2 in.	5 ft. 2 in.	5 ft. 10 in. 5 ft. 10 in.
Height above foundation	2 ft. $7\frac{1}{2}$ in.	3 ft. 3 in.	4 ft. 0 in.	4 ft. $2\frac{1}{2}$ in.	5 ft. 0 in.	5 ft. 3 in.	6 ft. 0 in. 6 ft. 0 in.
Diameter of flywheels	3 ft. 4 in.	4 ft. 2 in.	5 ft. 0 in.	5 ft. 6 in.	6 ft. 6 in.	7 ft. 0 in.	8 ft. 0 in. 8 ft. 0 in.
Diameter of shaft	4 in.	5 in.	6 in.	6 in.	7 in.	7 in.	8 in. 8 in.

The small pipe (7) between the receiver and the compressor is part of the automatic and adjustable unloading device for air and steam, by means of which the speed of the engine is regulated according to the pressure of the air in the receiver. When the pressure of the air exceeds the desired point in the receiver the steam is automatically throttled, and only enough admitted to keep the engine turning round, and another function of this device is to prevent the compressor from stopping or getting on centre, which it is liable to do when working at a slow speed.

A constant stream of cold water should be kept flowing through the water jacket which surrounds the air cylinder.

Upon the air receiver there is fitted a safety valve and a pressure gauge. This latter is placed for con-

venience close to the steam gauge (9) on the boiler side, so as to be well in view of the engine-man. The air pipes are connected to the receiver at 10, and below them is a blow-off cock, through which any water which may have condensed is driven off.

The receiver may be made of an old boiler, provided it will stand the pressure. It should be placed as near the compressor as possible; but if a long length of pipe intervenes between the receiver and the drills, it will be found advantageous to put another small receiver as near the main junction for the drills as is convenient.

Although the type of the compressing plant varies but little according to the different makers, the general dimensions differ largely with the amount of duty required from it.

I have seen them at work in Colorado and Nevada, U.S.A., where this arrangement is a favourite one. A plant of this type has recently (1901) been erected at the Clitters Mine, Gunnislake, Cornwall.

For very large permanent installations, such as that described on page 175, the compressing cylinders are attached in the rear of those of a high-class engine, such as a Corliss compound condensing, when, of course, a greater economy of working can be attained.

The Pierrefitte Air Compressor.—As illustrating an electrically driven air compressor, I will describe one which I erected at the Pierrefitte Mines, in the Pyrenees, in 1890, shown in figs. 117, 117A (Plate III.).

The air compressor (F) was built by Messrs. Schram & Co., of London, and is supplied with Schram's patent inlet and outlet valves. The cylinders are 14 in. diameter × 24 in. stroke, driven through gearing by means of a belt from the electromotor (D). It was found that the noise of the gearing in practice was too great, and on a future occasion I should specify either for helical teeth or a wooden toothed pinion. The speed at which the crank shaft was set to run was 80 revolutions per minute, but this was afterwards reduced to 63 as the compressor supplied more air than was required by the drills. This illustrates one of the disadvantages of electromotors, their speed is regular up to the maximum load, and will not vary according to the demands for air made by the drills. In order to reduce the speed from 80 to 63 on the crank shaft, a set of resistance coils was put in circuit which absorbed the excess of current and which could be switched out whenever it was desired to increase the speed.

The electromotor driving this compressor is shown in fig. 321 (page 495), and was made by Messrs. Schneider & Co., of Creusot. It runs at a speed of 450 revolutions per minute, and works with a current of 115–120 amps. at 680–700 volts developing 100 horse-power.

Thecompressed air was collected in the receiver (C), and was distributed to different portions of the mine from the stop-valves (J, H). The receiver is provided with a safety valve, and it would be well to place this valve

outside the compressor house, both because of the noise caused by the escaping air, and because the air carries with it minute particles of oil, which finally settle on the machinery and interior of the compressor house.

This plant is working most successfully running 10 drills, and it is also intended to install in the mine a diamond prospecting drill, which would also be driven from air supplied by this compressor.

As the compressor is situated high upon a precipitous hill, the receiver was made in four sections, with rivet holes bored and marked so that when the sections arrived they were placed together, each hole being absolutely true and then riveted together on the spot.

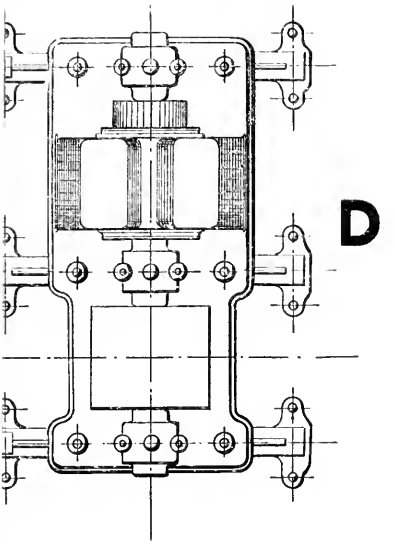
The Cwmystwith Air Compressor.—In Plate IV. will be seen the arrangement I used at the Cwmystwith Mine in North Wales for driving a pair of Schram's 6-drill compressors (F) with cylinder 12 × 24 by means of the surplus power from a 168 horse-power Pelton wheel (D), made by Messrs. Gilbert Gilkes & Co., of Kendal. E shows the water supply valves and speed regulator; C the belt pulley for driving the air compressors; while A is a grooved cable pulley supplying 100 horse-power by wire rope as supplementary power to a concentration mill as will be found described on Plate II. (page 18) and Plate XIV. (page 454). By means of the clutch (B) either the air compressor or the mill could be thrown on or off or both worked together; G is the air receiver; H the air pipe to the drills in the mine; and J the safety valve.

This arrangement worked very successfully. The head of water is 740 ft., and a portion of it is taken away at E for the purpose of driving a 15 horse-power Pelton and dynamo, as described on page 19. The whole is fixed on masonry foundations and covered with a corrugated iron shed to protect it from the weather. The waste water from the Pelton supplies the mill with washing water for the concentration machinery.

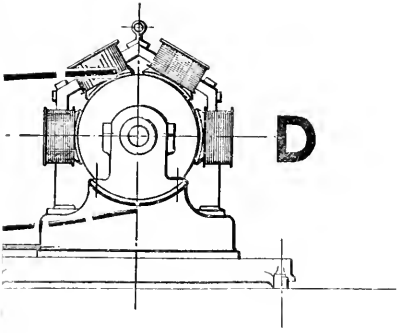
The Riedler Air Compressor.—In air compressors of the ordinary type, the inlet and outlet valves are opened automatically by the pressure of the air against the action of springs, which must be of sufficient strength to close them against the currents of air passing them. If the valves are heavy, the springs must also overcome their inertia; combining these forces, the action of the springs causes the valves to oscillate violently when they are open, which not only restricts the area of opening, but destroys the valves and seats themselves.

To mitigate these evils, the number of valves is increased, which results in extra cost of manufacture and maintenance.

Since their motion at moderate speeds is so violent, high speed is practically out of the question, and wide seats become necessary to prevent undue wear and tear, which, while prolonging the life, introduces another serious evil, which may be described as follows.



[PLATE III.



fitte Mines.

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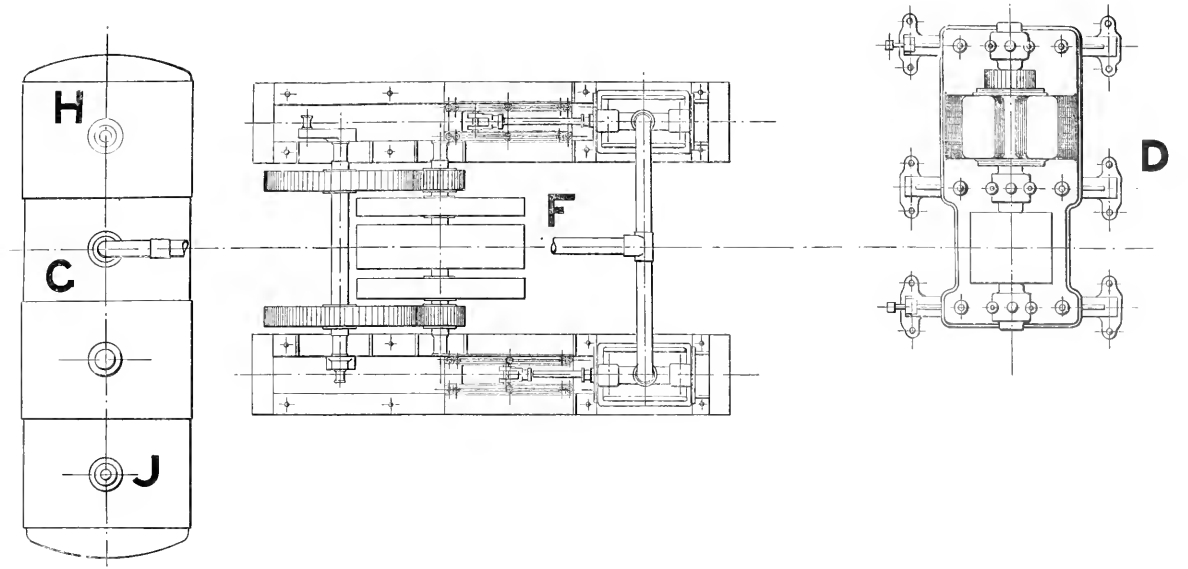
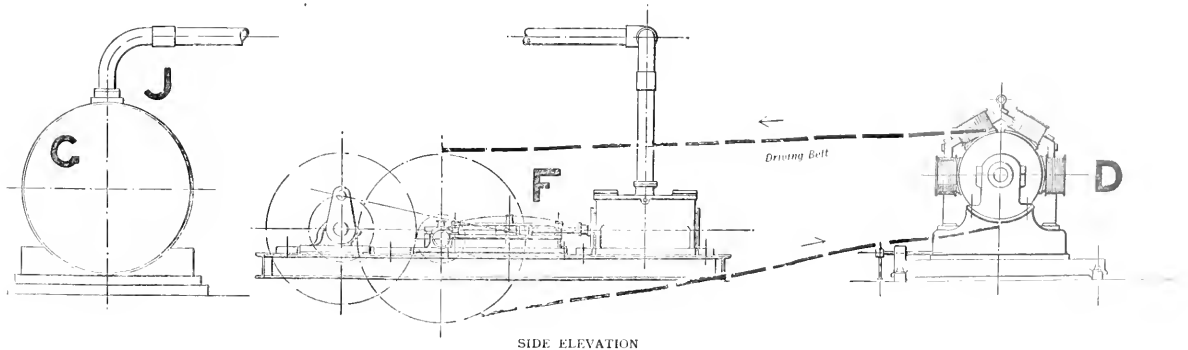
PLAN





SIDE ELEVATION

Figs. 117, 117a.—Air Compressing Installation (with Electromotor) at the Pierrefitte Mines

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Suppose a valve, which is 5 in. in its outer, and $4\frac{1}{2}$ in. in its inner diameter, to be seated during the compression portion of the stroke, and that the pressure in the discharge chamber is 75 lb. per square inch.

The pressure in the cylinder must rise to an amount, which, acting on $4\frac{1}{2}$ in. diameter or 15·9 in., will overbalance 75 lb. on 5 in. diameter or 19·64 in. To do this requires a pressure of $19{\cdot}64 \times 75 \div 15{\cdot}9 = 92{\cdot}5$ lb. per square inch before the delivery valves can open.

This causes them to open violently, and results in a loss of power during the delivery portion of the stroke.

It is precisely at this point that the advantages of the Riedler valve gear are brought into play; for while it on the one hand allows the use of springs to be entirely dispensed with, on the other it allows a full and uncontracted passage for the air with the minimum valves, which are of the most perfect type and of practically indestructible material. By these means the compressor can be run at a speed hitherto thought impossible.

The Riedler compressor, as constructed by Messrs. Fraser & Chalmers, Limited, can be attached to any motive power, and in fig. 119 is shown in tandem behind the cylinder of a Corliss engine which gives a clear idea of the valve gearing both of the compressor and the engine, while in fig. 120 is seen a section through the engine and compressor cylinders. These illustrations are those of a compound air compressor to which further reference will be made after the description of the valves has been finished.

The general view in section of a Riedler air compressing cylinder, as in fig. 120, shows that only one suction and one delivery valve is used at either one, and this simplifies both the construction and the operation.

The chest at each end of the cylinder is divided vertically into two parts, one side containing the air inlet, and the other side the air outlet valve, while ample room is left for the inspection and removal of the valves and valve seats.

The construction of an outlet and an inlet valve is shown in the sections (fig. 121 and 122). The seats are made of a hard mixture of iron, with narrow faces for the valve seats. The valves themselves are machined out of a solid steel forging in one piece, while at the outer ends there are capacious dash pots.

The Valve Gear.—Bearing in mind that there can never be any obstruction to the full opening of the valves, and that this gear only closes them, an inspection of fig. 119 shows the extreme simplicity of the means employed to effect this operation.

A cam with hardened steel faces is fastened to the wrist plate of the steam cylinder, and moves the rod attached to the air valve gear by means of two hardened steel rollers.

The extreme movement is only $\frac{7}{8}$ in. the proportions of the cam

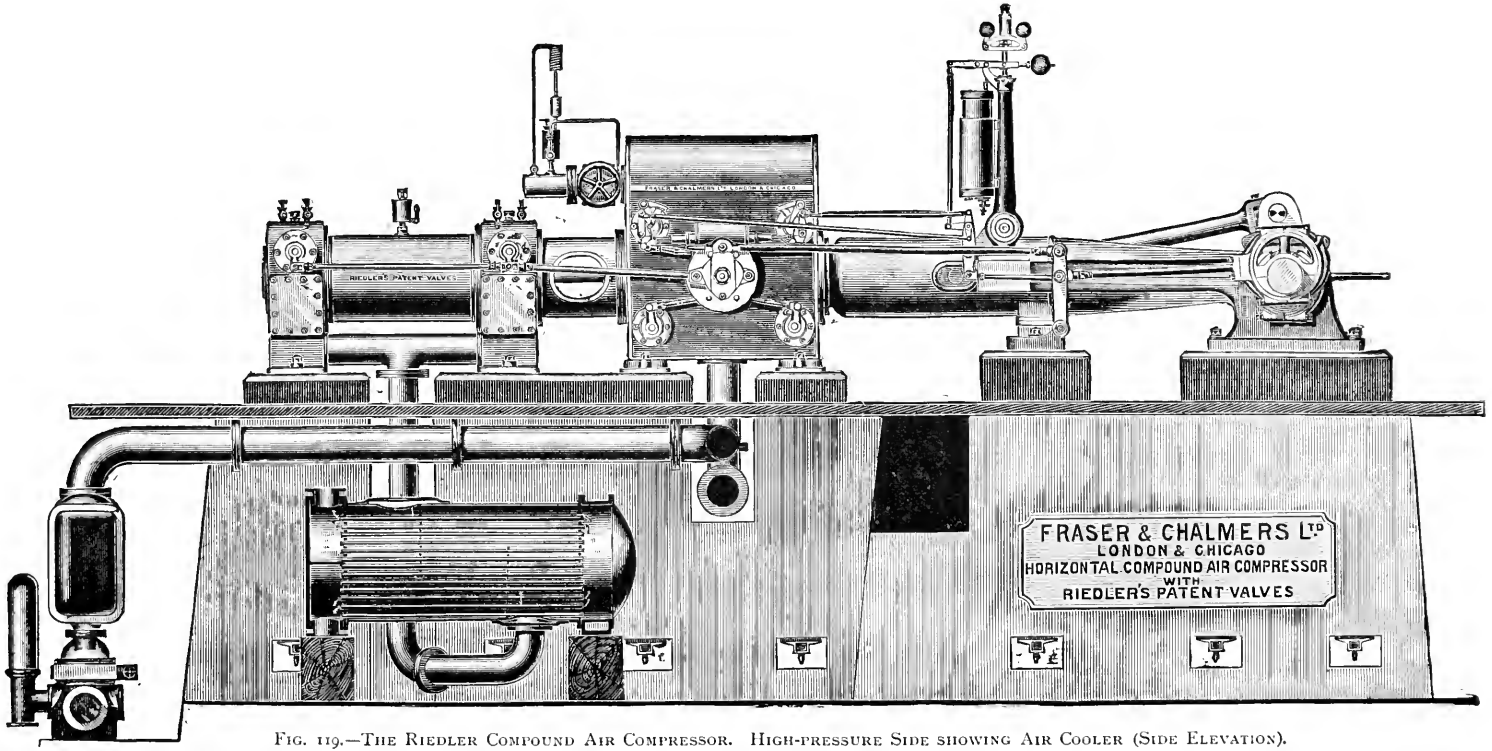
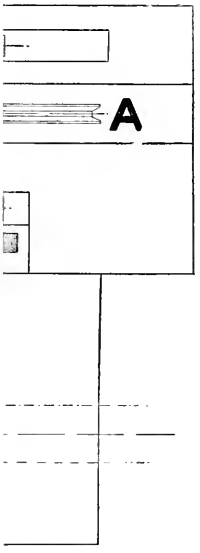
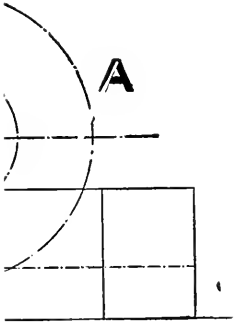


Fig. 119.—The Riedler Compound Air Compressor. High-pressure Side showing Air Cooler (Side Elevation).





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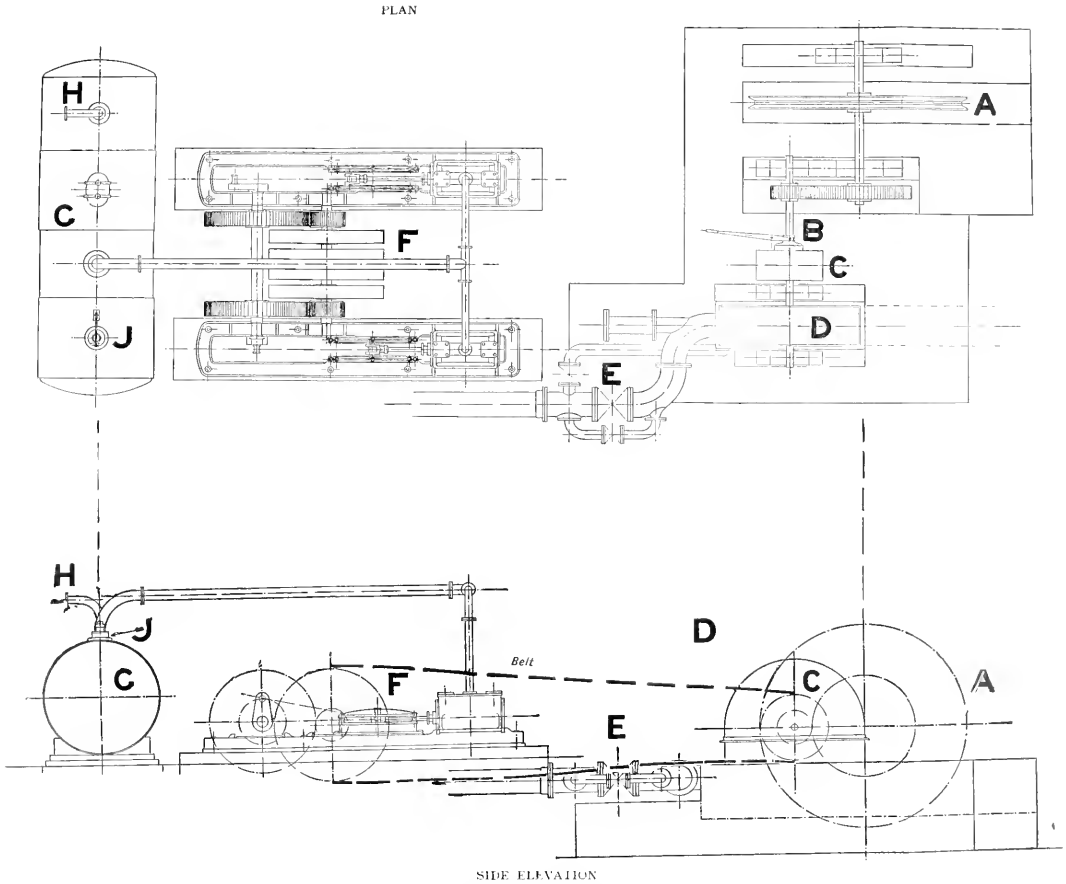

Fig. 118.—The Air Compressing Plant at the Cwmystwith Mines.

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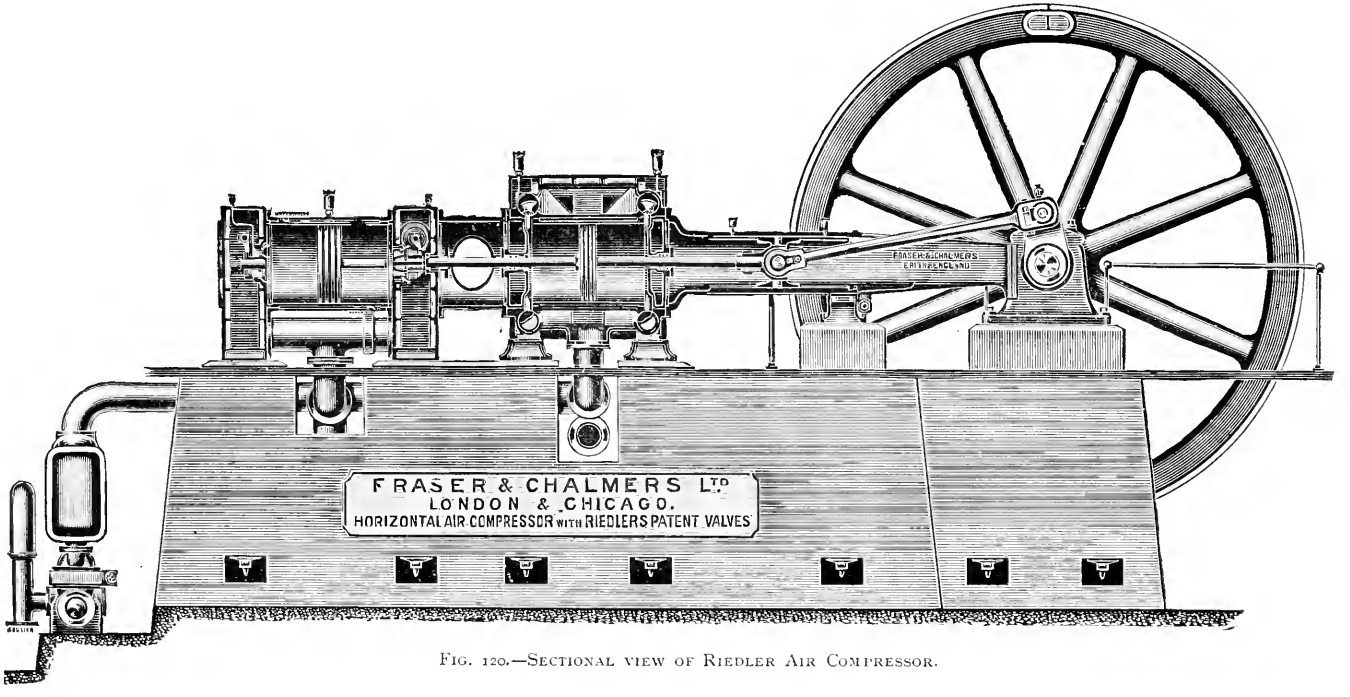


FIG. 120.—SECTIONAL VIEW OF RIEDLER AIR COMPRESSOR.

being such that the motion, while abrupt, is one of *gradual acceleration and retardation*, similar to that of a piston.

Both the cam rollers are always in contact with the cam, consequently lost motion is impossible, and as the total movement of the rod is effected in a small arc of the wrist plate motion, at a time when the wrist plate is moving at its greatest velocity, while the air piston is nearly at a state of rest, it is patent that the valves are closed at the most favourable moment, without restricting the natural flow of air in the least.

Each inlet valve being closed at the same time as the opposite outlet valve, the theoretical velocity of valve movement at the point of closure being zero, there is *no wear nor shock* on the valve faces and seats.

These are accordingly made extremely narrow, and, while *always remaining tight*, are almost indestructible.

No springs nor loose pieces are employed whatever in this gear, consequently the speed of operation is dependent only on the practical speed at which the steam engine may be operated.

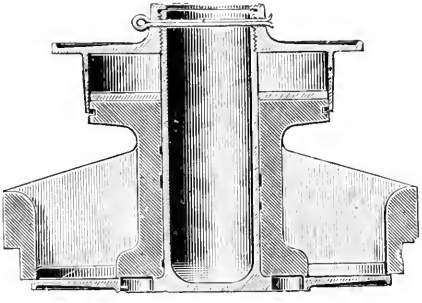


FIG. 121.—THE RIEDLER INLET VALVE.

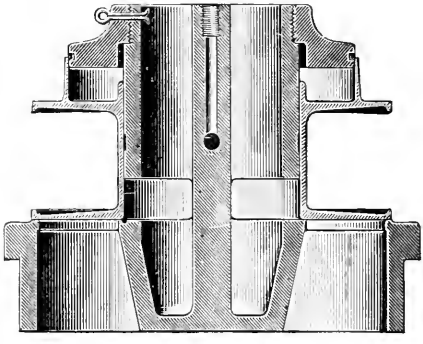


FIG. 122.—THE RIEDLER OUTLET VALVE.

Speed Governor.—In addition to the usual speed governor, it is necessary to provide one that shall control the speed of the compressor in exact accordance with the amount of compressed air required, the speed governor only acting when the limit of safe working has been reached. To accomplish this result a floating lever is added to the ordinary governor, one end of which is attached to the cut-off mechanism, and the other to a plunger working in an oil cylinder. This arrangement will be seen by reference to fig. 119. The position of this plunger is controlled by the air pressure working against a spring. Should the air pressure exceed the normal limit, the plunger moves upwards against the spring, and thereby alters the cut-off on the steam cylinder to an earlier point. Similarly should the air pressure fall below the normal, the spring lowers the plunger and increases the speed of the engine.

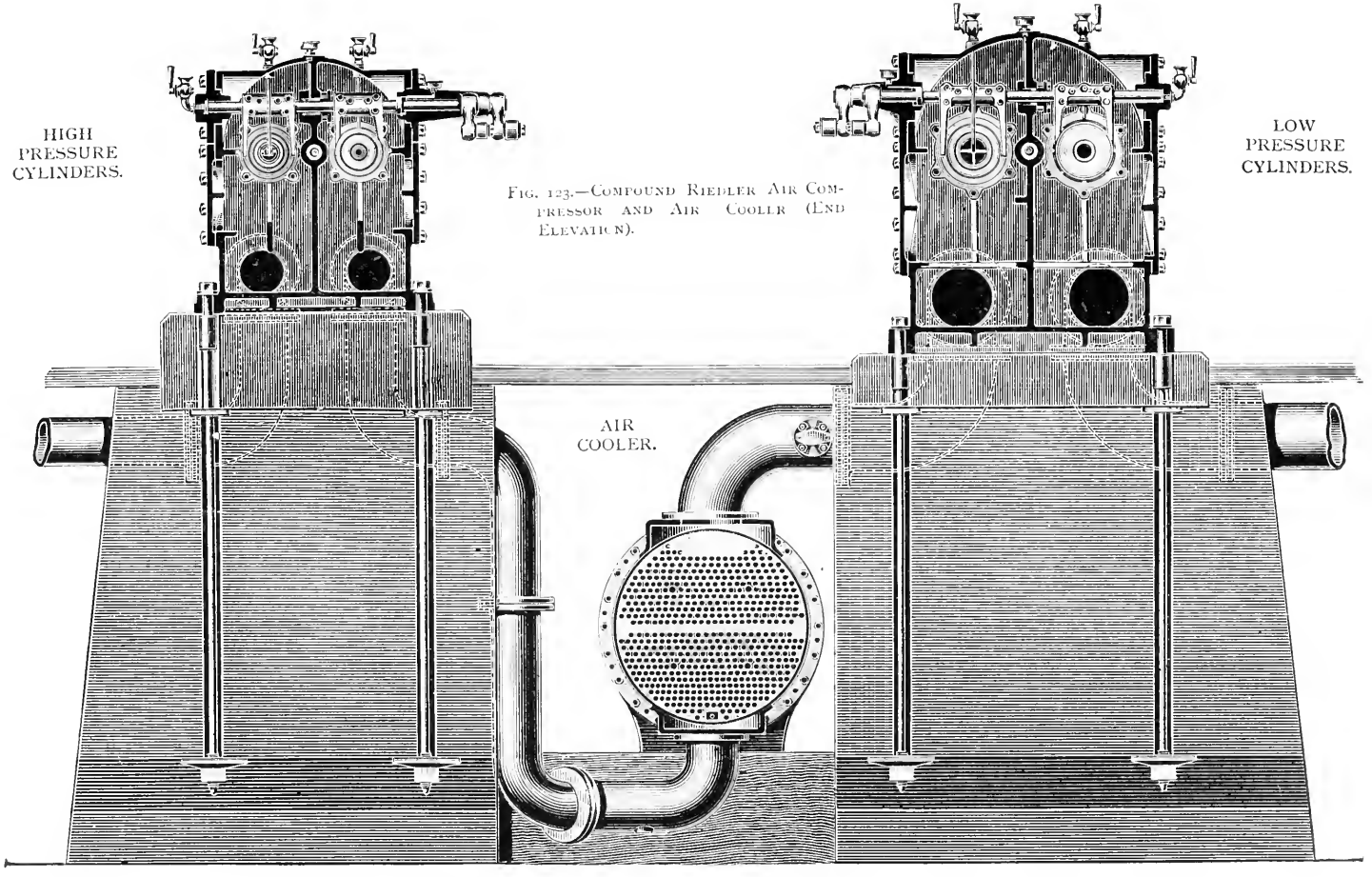


FIG. 123.—COMPOUND RIEDLER AIR COMPRESSOR AND AIR COOLER (END ELEVATION).

There is thus constantly exerted a force on either side of the controlling plunger, assisted by the greater or lesser resistance in the air cylinder itself; and the speed of the machine is thereby automatically varied to suit the amount of compressed air required.

Compound Air Cylinders.—The merits of compounding in steam cylinders hardly need recapitulating here, though it may be stated that even compounding in steam cylinders is hardly to be advocated for air compressing, when fuel is moderately cheap and less than 100 I.H.P. required and sufficient water for condensing not available. The reason for this is that with a duplex air compressor either side may be used independently of the other. This it would be difficult to do with a compound engine, as it would require a low pressure cylinder of unusual strength and special valves and connections for modifying the steam pressures.

If, however, the power required exceeds 150 I.H.P., then there is a fourfold advantage in compounding both in the steam and in the air cylinders—namely, (1) economy of power; (2) increase in capacity; (3) less loss of leakage; (4) reduction of strains in the machine.

In figs. 119, 120, 123 will be found general views of a compound steam and air compressor, with the air cooler fixed between the foundations supporting the low and high pressure cylinders.

The low pressure air cylinder is placed behind the low pressure steam cylinder, and in this the air is compressed, say to 36 lb. per square inch; and passing through the air cooler is drawn into the high pressure air cylinder, which is behind the high pressure steam cylinder, and is here further compressed up to 90 lb. per square inch.

The suction pipe to the low pressure air cylinder should be led from the coolest part of the building and where the air is free from dust.

The following table gives the general dimensions and capacity of compound steam and double stage air compressors of the Riedler type, fitted with steam jacketed cylinders and metallic packing throughout.

Steam Cylinders.		Air Cylinders.		Str.	R.P.M.	Cubic Feet Free Air per Minute.	Maximum I.H.P. Required.
H.P.	L.P.	H.P.	L.P.				
Inches.	Inches.	Inches.	Inches.	Inches.			
12	19	14	22	36	90	1370	200
14	22	15	24	36	85	1540	226
17	27	18	28	36	$83\frac{1}{3}$	2280	300
19	30	20	31	42	75	2640	388
20	34	20	33	48	68	3100	457
25	40	24	39	54	65	4150	685

Increased Capacity by Compounding.—Many elaborate arrangements of cylinders and valves have been devised to reduce clearance in

compressor cylinders, and often other desirable adjuncts sacrificed to attain this point, in itself of little or no importance. The following description of the results obtained by compounding ore from an exhaustive series of experiments carried out by Messrs. Fraser & Chalmers, Limited, and confirmed afterwards by actual practice.

In small air cylinders, a slight increase in the cylinder diameter makes up for the loss by clearance, the work in both cases remaining the same, since the air compressed into the clearance space gives out useful work during its expansion at the next stroke.

With larger cylinders, compounded, the capacity of the whole machine is determined by the volume of air drawn into the low pressure cylinder per stroke, where, as it is only compressed to a moderate amount, the loss in capacity by expansion is correspondingly small.

The high pressure cylinder obviously must compress whatever air is delivered by the low pressure, therefore the only effect of its clearance is to vary the relative amounts of work done by each cylinder.

Reduction of Leakage.—In a single cylinder machine, both valves and piston are subject to the full difference in pressures each stroke, while in a compound machine the low pressure valves and piston have only a maximum difference of 20 lb., and the high pressure a maximum of 55 lb. per square inch; also, any leakage of the high pressure part does not restrict the capacity of the whole machine, but merely puts additional work on the low pressure piston, the total amount of air delivered remaining the same as though no leakage took place, but merely effecting the relative proportion of work done by each cylinder.

The advantages of double over single stage compression may be accurately determined by reference to the air card (fig. 124) which illustrates the scale of pressure and work during single and double stage compression.

A B represents the volume of a cylinder in which the compression is carried to the final point, and it also will serve as the low pressure cylinder for a double stage machine—C D in the latter case representing the volume of the high pressure cylinder. A E represents 3 per cent. clearance in the large, and C F that in the small, cylinder.

We will now suppose that it is desired the compression shall take place entirely in one cylinder. The piston moves from A to B drawing in air at 15 lb. or atmospheric pressure. At B it returns, compressing the air along the curve (B G H), on or near the adiabatic line.

At H it is discharged into the final receiver at 75 lb. gauge, or 90 lb. absolute pressure, and at a high temperature; the piston continuing to I, where it then begins the return stroke.

The discharge valve now having closed we have the volume (A E) filled with compressed air, which expands to the point (J), and as

the volume is small, and the velocity slow, we may assume that the expansion follows the isothermal curve, since the piston and cylinder end are at this time at a high temperature, and impart their heat readily.

For succeeding strokes the fresh air taken in is only the volume (J B) instead of A B, and the capacity for taking in fresh air is now only 85 per cent. of the whole cylinder volume.

This decrease in volume, however, is not accompanied by a loss of power, since work equivalent to the area (A I J) is given back by the air in the clearance space, and therefore the only loss is in capacity; the work performed during the cycle is now measured by the space (B G H I J).

Owing to the heat generated

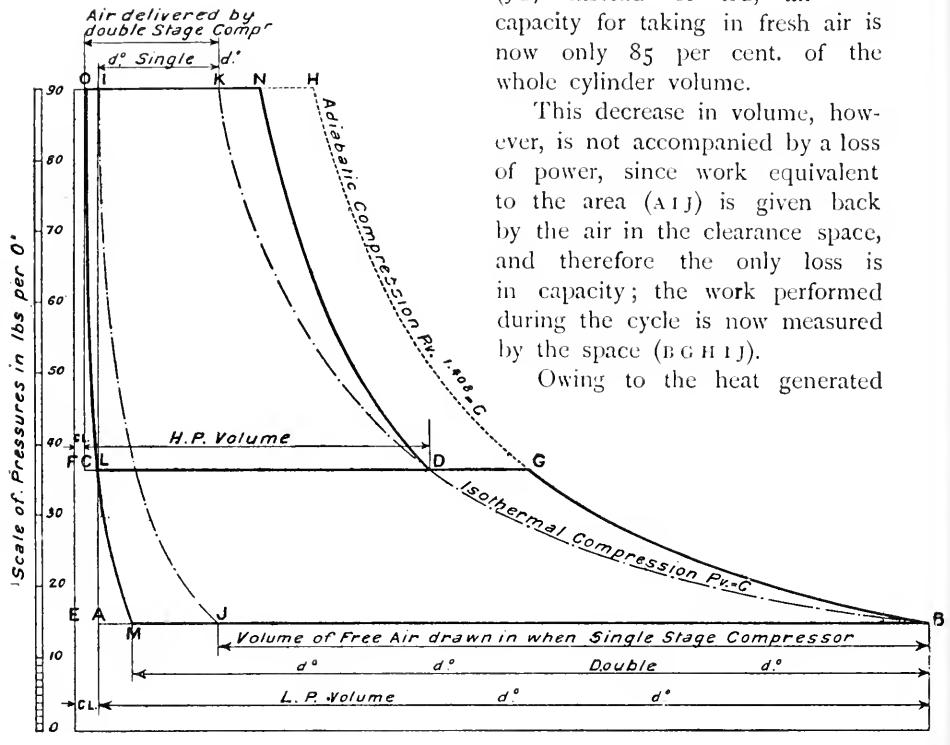


FIG. 124.—AIR CARD ILLUSTRATING COMPOUND COMPRESSOR.

during compression, the air at H nearly always shrinks to the point (K) before it can be utilised in the motor, the measure of work thus dissipated being the area (B G H K D).

We will now consider double stage compression, using the same cylinder as before for the first stage.

The air is drawn in till the piston reaches B, when it is compressed along the adiabatic curve as before, but only to the point (G), where it passes into an intermediate cooler on its way to the other cylinder. The piston moves on to L, the end of its stroke. The same clearness as before (F L) now contains air at $36\frac{1}{4}$ lb. instead of 90 lb. absolute pressure, which expands as before isothermally to the point (M), causing a loss in capacity of only $4\frac{1}{4}$ per cent. instead of 15 per cent. as in

the single stage; the amount of fresh air drawn in per stroke is now B M instead of B J, and J M represents the increase in capacity by compounding.

An important change in volume now occurs. The compressed and heated air at $36\frac{1}{4}$ lb. absolute pressure, in passing through the cooler to the second stage air cylinder, suddenly shrinks in volume from G F to D F, and it is only the latter amount of cooled air which must be raised to the final pressure.

The compression goes on adiabatically as before on the curve (D N), and is discharged at 90 lb. absolute pressure from N to O.

The useful amount of air discharged in the single stage machine is measured by the distance (K I), while in the double stage it is K O, or an increase of I O in amount, corresponding to the original volumes of fresh air drawn into the first stage cylinder.

The air at O now re-expands to L, and the cycle is complete.

Reviewing these operations, we find, by single stage compression the useful compressed air delivered is measured by the distance (K I) or the free air by B J; the work done is measured by the area (B G H I J) In double stage compression, the useful air delivered is measured by K O, or the free air by B M; and the work done by the area (B G D N O L M); or there are required 5552-ft.-lb. to compress one cubic foot of free air to 75 lb. gauge pressure, in a single stage, and 4500-ft.-lb. per cubic foot in a double stage compressor, which represents an economy of 19 per cent. in the power required in favour of the latter machine.

Supporting Columns, Tripods, and Carriages.—The tunnel or levels ordinarily used in mining are but small, and the space available for machinery and the handling of the various appliances is very limited.

FIG. 125.—SINGLE SCREW COLUMN FOR SMALL DRIFTS AND SHAFTS.

For this reason the supports upon which the rock drills are fixed must, as a general rule in mining, be strong, but light and portable, in order that they may be readily removed previous to each blast.

The support in ordinary use is a light steel column, as shown in fig. 125, fitted with a lengthening screw, by which it is tightened up either horizontally or vertically across the tunnel, a block of wood being always placed between the ends and the rough, uneven surface of the rock.

In tunnels of large sectional area the double-screw column (fig. 126) is used with the drill mounted on the arm. In small tunnels and shafts the single-screw column, however, is preferred, the drill being mounted directly on the column by means of the clamp (fig. 127), or the patent

Ingersoll-Sergeant clamp (fig. 128), in which the swinging jaw is brought to bear upon the cone on the back of the drill by means of a single bolt.

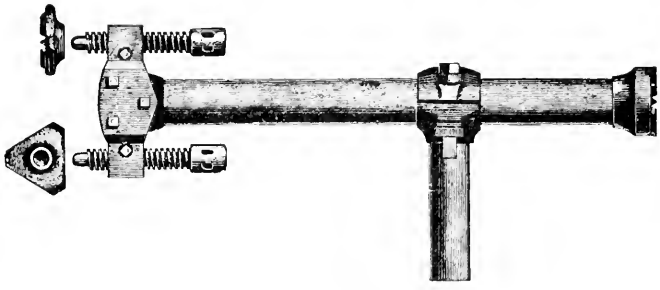


Fig. 126.—Double Screw Column with Arm.

The price of a $4\frac{1}{2}$-in. steel column, from 6 ft. to 8 ft. long, with arm and clamp complete for mounting, $2\frac{1}{2}$ in. to $3\frac{1}{2}$ in. diameter drills, is

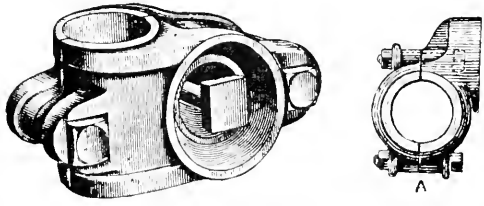


Fig. 127.—Clamps for Ingersoll Drill.

about £12, and the weight from 280 lb. to 300 lb. The double-screw column costs about 30*s.* less.

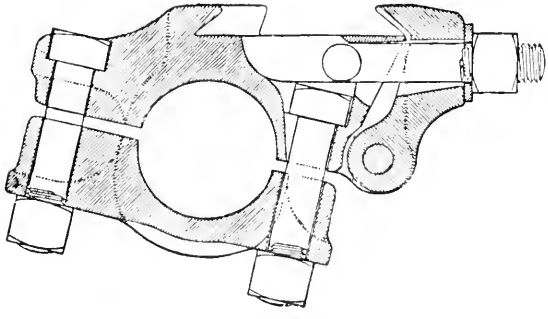


Fig. 128.—New Pattern Clamp, used for Holding the Sergeant Drill upon the Arm or Column.

The column or bar is, however, not suitable for mounting drills, except where the sides of the level are fairly close to each other, and, of course, for outside work it is altogether useless, so that some form of tripod must be used, the legs of the tripod carrying weights in order to insure

the rigidity and solidity of the drill. A convenient form, and one representative of many others, is shown in fig. 129. The legs can be moved in any direction and are telescopic, so that the tripod can be fixed in any position on the most irregular ground, and the drill adjusted to bore holes in any required direction, from vertical to horizontal.

The price of such a tripod, complete with weights, is, for a 3-in. drill, about £15.

For the driving of tunnels of large section, such as railway tunnels,

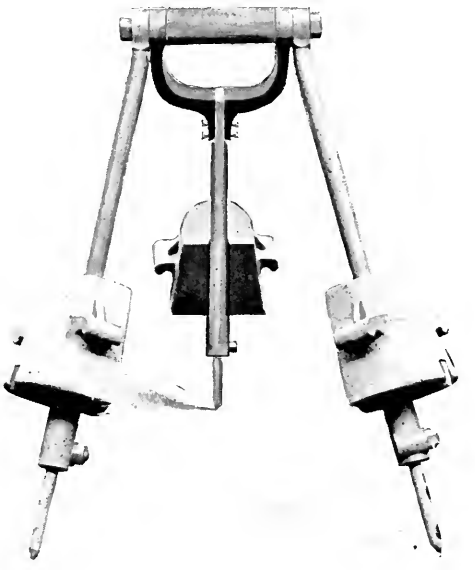


FIG. 129.—ROCK DRILL TRIPOD.

a special form of carriage support needs to be used, such as that illustrated in fig. 130, which was designed by Mr. Richard Schram, M.I.C.E., to carry four of his drilling machines for use in driving $2\frac{1}{2}$ miles of tunnel on the Khwaja-Amran branch of the Quetta Railway. The carriage carries two stretcher bars, each of which supports two drilling machines, the arrangement of the carriage and bars being such that trucks for the removal of *débris*, etc., can be run right through it, so that it is unnecessary to provide any sidings in which to run the carriage when the removal of spoil becomes necessary. This arrangement has the further advantage that the drilling machinery can be brought up to the working face before all the *débris* has been removed, thereby economising time. In cases where timbering is necessary, and the stretcher bars have to be lowered to clean up, arrangement is made whereby these, with their machines can be turned back down on to the carriage. The

small receiver shown on top of the carriage is for the distribution of air, and it has two inlets and four outlets, corresponding to the number of drills. The tanks shown on each side are the water injectors, the injection being effected by admitting air under pressure above the surface of the water. The tunnel for which the machines are designed will be driven not only from each end, but by sinking a shaft midway two additional working faces will be provided, making four points of attack.

The four sets of tunnelling plant required were all supplied by Messrs. Schram, amounting, *in toto*, to eight locomotive type boilers, four air compressors, with their receivers, four carriages of the type

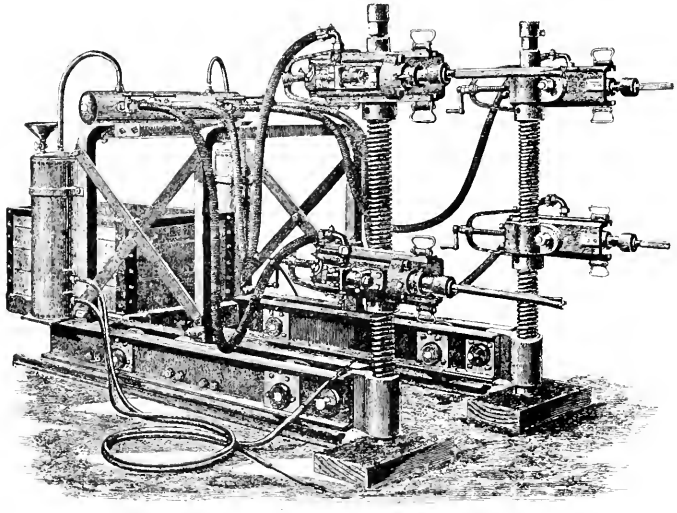


Fig. 130.—Schram's Rock Drill Carriage.

just described, and thirty-two rock-boring machines, with the accessories necessary for opening out the tunnel.

In mining proper, a tunnel of such large dimensions would rarely, if ever, be undertaken ; but I illustrate the method adopted in such cases because men accustomed to the use of rock drills are often drafted from their legitimate sphere to conduct works coming under the designation of civil engineering.

The drill hole, when the machine is at work, must be kept constantly full of water, not only in order to remove the chippings, but also to keep the point of drill cool. A water tank of iron mounted on a truck, and brought as near the working face as possible, is therefore a necessity. In fig. 130 this water tank is shown fixed in the carriage support, and surmounted by a funnel. The pressure of the air drives out the water through an indiarubber hose, with a fine brass nozzle into the hole

which is being drilled, and so fulfils the above-mentioned duties, and stops the formation of dust, which, with certain minerals, would be very deleterious to the workmen.

Steel Bits for Rock Drills.—There are many kinds of bits in use, each having its specific value when applied to certain kinds of work. There are also a great many notional bits, many of which are patented devices, but few of which have any value. Obviously the best bit for use is that which is the simplest in construction consistent with efficiency.

It may be stated as a general rule that the single-edged bit should be used everywhere that it is possible to apply it, so great is its simplicity. In hand drilling the single-edge bit is always preferred. It cannot be used with percussive drills in hard rock, because the blow is so strong that the edge will not stand. Here is where double edging comes in to advantage; for, having plenty of power behind it, we may distribute that power over two or three edges, and thus gain an advantage.

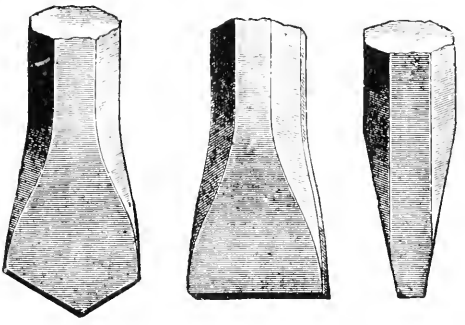


FIG. 131.—ROCK DRILL BITS.

A straight edge on a marble bit will result either in broken edges or in rapidly dulled edges, and in sticking. It is a curious fact that the point on the edge of a marble bit should not be in the centre, but a little to one side, in order to prevent sticking and to do the best work. The reason for this is seen when it is understood that the drill, in turning around after each blow, would, were the point in the centre, shape the bottom of the hole like a cone, while, with the point to one side, as in fig. 131, the shape is that of a truncated cone, which offers less chance to stick. The edge might be curved instead of tapering to a point, but the taper is preferred because more readily sharpened. The advantage of a taper or a curve is that it distributes the work more evenly.

A straight edge, when used for hole drilling, brings most of the work upon the outside points of the bit. These points turn around through the largest circle, that which limits the diameter of the hole; and, besides, they have to break up the stone at the wall where it offers the greatest resistance. The taper or curve eases this condition of things by changing the bottom of the hole so that it has no sharp corner.

The tapered single-edge bit does remarkable work in marble quarrying, and has been frequently timed while drilling holes horizontally at the

rate of 12 and 13 in. per minute, $1\frac{1}{4}$ in. in diameter, records of 350 lineal ft. of hole, all in holes of about 2 ft. in depth, having been put in horizontally in one day of 10 hours.

Where the marble or limestone is soft, the edge of the bit should be sharp, and in proportion as the stone is harder, the edge should be less acute, for the percussive drill, to do the best work, should strike with its full force; this it cannot do in hard rock with a single-edge bit of acute taper.

Sandstone has a singular effect upon drill bits. Though sandstones are usually soft, the bits cannot be finely pointed, but on the contrary should be flattened. A bit with a knife edge, when used in sandstone, will have its edge sharpened like a razor, the faces of the bit gradually becoming concave. This is natural, because, as the bit imbeds itself in the grit of the rock, it is rubbed as though on a grindstone. The stone is not usually hard enough to dull the sharp line of the edge, so that the more this bit is used the sharper it gets. It cannot, however, be used very long, because the points or outside ends of the bit become flattened and dulled, and, what is a still greater objection, the ends become tapered. All this arises from the hard work and the great rubbing experienced at the walls of the hole.

The most successful sandstone bit is undoubtedly that with the flat edge, shown in fig. 131. This bit is nothing more than a flattened-out piece of steel with no more edge to it than there is to the side of your finger. It is sometimes called the "stub" bit. Exact dimensions of this bit cannot be given that will apply in all cases, but the most popular dimensions are about $1\frac{1}{2}$ in. length of face and from $\frac{3}{8}$ to $\frac{5}{8}$ in. in width. The cutting face should be square and rectangular. This bit cannot be tempered in the blacksmith's shop, because there is too much metal in it, and it will flake and crack. It is usual to simply dress it up by heating it and hammering it to square edges, the chief work having to be done upon the outside ends in order to keep them square and up to gauge. When properly dressed it is thrown into a heap of ashes, or on the ground, without even putting it in water, except perhaps for an instant.

There is so much metal in the sandstone bit that it is not rapidly worn away by the grit. It is, therefore, a common thing to see one of these bits in use for half a day, drilling a great many holes in different places, without having to be sent to the shop. When starting a hole it pounds upon the rock like a bass-drum, and an inexperienced looker-on would naturally suggest a sharper edge.

There is no question about the advantage of the flat bit in sandstone quarries, so far as the blacksmith's work is concerned. It will actually put in a hole faster, and it does it because, when drilling sandstone, the process is not a chipping but a crushing one. Marble, or any other hard crystalline substance, needs a sharp edge to throw a chip, but sandstone will crush.

Percussive Drill Bits.—Prior to the use of the percussive drill there were few, if any, drill bits, which had much value above that with the single edge. Even in artesian well boring, where the blow is heavy, the single-edge bit has held its place against many patented bits.

The illustrations in fig. 132 show a modified form of single-edge bit in comparison with several other bits which are used with success with percussive drills. The flattened or grooved shape given the single edge at its centre, is for the purpose of discharging the cuttings. As the centre of any bit performs but little work, it may readily be cut away

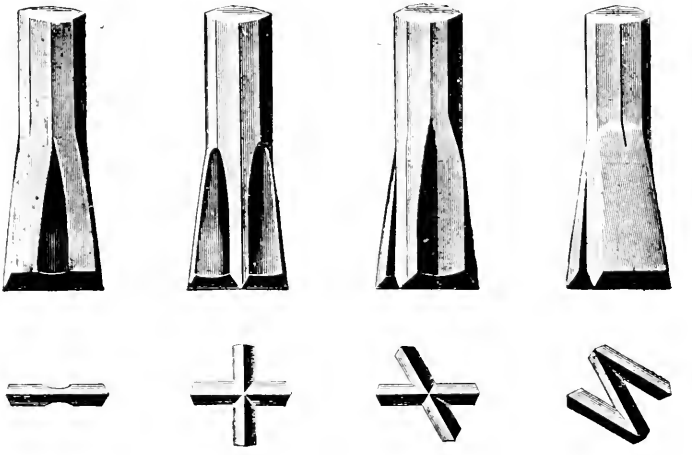


FIG. 132.—ROCK DRILL BITS.

without reducing efficiency. The other three illustrations shown herewith are the +, the X, and the Z bits. It may safely be said that, apart from the various forms of single-edge bits, previously described, these three are the only really important bits in use with percussive drills.

The + bit is the most popular percussive drill bit in use. It seems to be a happy medium, in that it accommodates both the drill runner and the blacksmith, though we are quite sure that were the blacksmith's wishes not consulted, the X bit would replace it almost everywhere. Out of several hundred inquiries recently sent out among mining and quarrying men as to which bit was preferred—the + or the X—opinions differed largely, but the weight of evidence was in favour of the + bit.

It may be stated as a general rule that the X bit will do good work in *any kind of rock where the + bit is used*, but the + bit *cannot be used to advantage in some rock where the X bit gives satisfaction.*

Another rule is, that the + bit had better be used wherever the rock will admit, for the simple reason that it is more readily dressed by the blacksmith.

The two bits are very much alike in that they have the same extent of cutting edge, but they differ in that the edges in one case cross at right angles and the other at acute angles. As the bit when at work turns round after each blow it is obvious that in the case of the + it may strike four times in the same place while turning the circle, while with the X it can only strike twice in the same place. A + bit when turned one-quarter of the circle, or 90°, may imbed itself in exactly the same groove that had been made by a recent blow; and if this striking in the same place is frequent, and the rock is soft enough to admit of rapid drilling, the hole will become "rifled"—that is, it will not be round. Any one who has much to do with drill holes knows that a "rifled" hole is a great nuisance. As the X bit has only half as much chance to strike in the same place as the +, it offers only one-half the opportunity to "rifle" the hole. It is a common thing for percussive drill manufacturers to receive complaints that "the drill will not put in a round hole"; the invariable remedy is to change the bit, and as a general thing the X bit is the thing to use.

At the quarries of the Brainerd Quarry Company, Portland, Conn., a $3\frac{1}{2}$ in. cylinder steam drill is used constantly, putting in holes about 5 in. in diameter with the X bit. These holes are perfectly round. The + bit has been tried, and has failed. At St. Paul, Minn., several holes have recently been drilled for electric poles, the drill cylinder being 5 in. in diameter, and the holes drilled with an X bit are each 7 in. in diameter.

In the blacksmith's shop the + bit is invariably preferred. In using the dolly the blacksmith finds that by turning it one-quarter it fits the bit, and, owing to the rectangular and uniform construction of the bit, he has no difficulty in keeping it at gauge, while with the X he must turn his dolly one-half the circle, and in doing so the bit must either be turned round, or he must send his helper on the other side of the steel. It is because of *this very condition of things as illustrated* in the blacksmith's shop, the X bit when turning around in the hole is *less liable to strike in the same place and drills a better hole.* Persons using the + bit and having difficulty with "rifled" holes can try the experiment by simply knocking the flanges of the bit together in the blacksmith's shop while the steel is hot and after it has been dressed. If they find that this bit will drill a more satisfactory hole, they had better throw away their + dolly, and send for an X, the blacksmith to the contrary notwithstanding.

In trap rock, granite, and other uniform rocks the + bit does good work, and drills a round hole because the rock is uniformly hard, and the drilling is consequently slow.

The Z bit, shown in the illustration, is designed and used to a moderate extent in soft rocks, or in work where seams and soft places

are found in the line of the hole. This bit is sometimes modified by having the middle edge straight across, thus making an H instead of a Z, but there is little preference between the two, and either one is bad enough for the blacksmith to dress.

To summarise, in gneiss and homogeneous rocks free from faults, the ordinary chisel-shaped bit is to be preferred, as it, perhaps, in such rocks, cuts faster than any other shape of bit, and smiths can more readily sharpen it. In schistose rocks wherein layers of uneven hardness, with numerous fissures are encountered, the chisel bit does not answer so satisfactorily, as the drill seeks the softer material, gets out of line,

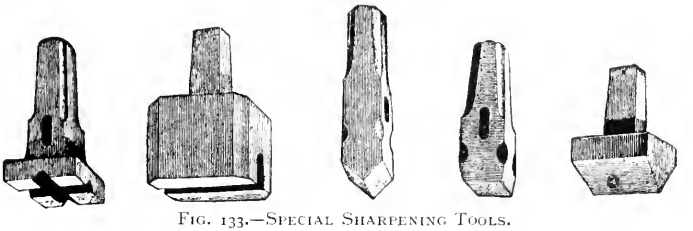


Fig. 133.—Special Sharpening Tools.

sticks fast in the holes, and much time is lost in extricating them, and unnecessary jar and strain thrown on the machine. In such ground, to obtain the best results from machine drilling, the chisel bit should be replaced by the cross, of which there are two varieties, the + and X, shown in fig. 132. For the softer rocks the cutting edge can with advantage be made Z shaped.

The quality of steel used in the tool bits requires careful selection, as will be readily conceded when we mention that at 4 atmospheres effective pressure a 3-in. diameter cylinder drill will deliver up to 700 or 800 blows, each of 175 ft.-lb. per minute, and the best brands of tool steel are required to stand this severe strain in hard rock. Steel bars can now be obtained of a cruciform or + section, and this I have used with great success. The grooves in the bars serve as channels to carry away the débris, and thus prevent the drill from striking.

The drill bits, according to size of hole to be bored, should be made from $1\frac{1}{2}$ in., $1\frac{1}{4}$ in., $1\frac{1}{8}$ in., and 1 in. octagonal or round steel, and care must be taken in changing and that the bit to follow fits easily and revolves freely in the hole. The borers should be sharpened in successively diminishing diameters, and a distance of $\frac{1}{8}$ in. in each successive tool will generally be found sufficient.

The peculiar shaped bits used for rock drilling require the use of special tools in the blacksmith's shop, in order that they can be made and dressed without difficulty.

These tools are shown in fig. 133, and may be purchased ready made for about £2.

Directions for Working Rock Drills.—The rock drill is the machine above all others which is most subjected to rough treatment; the more so underground, where, because of the bad light and want of space, and also from the inexperienced hands in which it is often placed, it gets more knocking about than is good for any machine not constructed on the soundest model and of strongest material.

In some kinds of rock the bits are very liable to stick, and then the workman hammers at it or the drill with whatever happens first to come handy. A blow from a hammer is the quickest way to release a drill, and will do no harm to a first-class machine, but the blow should be given on the drill, and not, as oftens happens, on the piston rod or the machine itself. One of my own troubles when running rock drills in a mine in the South of France, where the miners are a hot-headed mixture of Spanish and French blood, arose from the men striking the stuffing box of the drill when the bit stuck, often breaking it, accidentally perhaps; but as this involved a delay for changing the machine, it is doubtful whether the damage was not sometimes maliciously inflicted. And in that particular mine it happened that the miners were much against the introduction of machine labour for stoping.

It is difficult to find and train men fit for the work of running a drill. What is wanted is a man of energetic, ingenious turn of mind, and possessed of much patience, who will take a pride in overcoming the difficulties in the way, and not be happy till he has done so. At first such a man may lose time by puzzling over the job, but once he gets to know his machine he will not readily be put in a fix; but it is always advisable to have at hand an experienced man able to initiate the others at the outset.

As soon as a drill gets out of repair or refuses to work it should be sent to the surface at once, for it is only loss of time to overhaul it underground, and will lead to the loss of some of the fittings.

The man who works the machine must also know how to place the hole to the greatest advantage, so as to produce the greatest effect with a minimum of explosive, and then fix the support where it will enable the rock drill to command the greatest number of holes.

In operations for tunnelling, when several drills are run on a carriage, and rapid advance is the primary consideration, it is best to place the holes on a regular system, in which case electric blasting should also be adopted. Fix the mounting firmly and securely, and if the tripod is to be used, with a small hand drill and hammer, notch in the rock a place for each leg. Never omit this, otherwise the vibration will cause the tripod to travel, and thereby bring the borer out of line with the hole, necessitating probably a restart, followed generally with dire abuse on both drill and tripod, when the fault is solely due to the omission of a simple and obvious precaution on the part of the operator.

If the column or stretcher bar is to be used, place a block of wood between the rock and one end of the mounting bar, as shown in fig. 125; a block, however, between each end of the bar and the rock is to be preferred. Fix the bar firmly and rigidly between the walls by the jack-screw. Having secured the column in the required position, place the rock drill on it, as shown in the illustration, set the machine to the desired position, and secure it by the cap and bolts provided for that purpose; then square off the rock where the hole is to be placed at right angles to the travel of the borer. This, especially in hard and fissured rock, should be carefully attended to, otherwise the jumper under the heavy blow will on striking the rock glance aside and not cut down the inner edge of the hole in line with the travel of the borer. This deviation, if unattended to, will gradually carry the bit so much out of line as to waste the whole effect of the blow in friction, whereupon a bit with a smaller cutting surface must be inserted. In fissured and troublesome rock, however, when the drill is allowed to get out of line at the start, it will often cause trouble throughout the whole hole, whilst a *hole well started is half bored.*

Having squared the rock off and everything ready for a start, put in the shortest borer, draw out the piston rod until the piston head strikes the bottom of the cylinder, and screw forward the drill until the borer touches the rock, and then give the feed screw a couple more turns. To fix the borer in its conical seat in piston rod, all that is required is to force back the piston rod and draw it smartly forward, striking the bit against the rock. Blow air through the hose to remove any dirt and grit that may have accumulated, close the stop-cock, pour some oil in the connector, bend and connect the hose to the machine. Oil the rotating gear by removing the screw plug which is provided in the top cover for that purpose, and the machine is ready to start.

Turn air on to the hose from the main, open the stopcock half way, when the machine will start, and *at once commence* cutting the rock, and as the borer penetrates the rock the machine must correspondingly be fed forward by the feed screw. When 4 or 5 in. are bored turn on full air, pour water freely into the hole, and advance the drill by the feed screw according to the rate of penetration. When the short drill has cut as deep as it will reach, stop the machine, screw it back by the feed screw, remove the borer, and replace it by the next longer length; *strike the first few blows at half pressure, to bring the bottom of the hole to the shape of the drill*, then full speed until the bit has bored as far as it will reach, when again replace it by a longer length, and so on until the required depth is attained.

In running *a new rock drill with steam*, it may sometimes happen that the machine will not start readily, or, after a few minutes, work at

a low speed; this is caused by the unequal heating of the cylinder, and will disappear as soon as the machine becomes uniformly heated.

When starting a machine that has been laid aside, and also a new one, pour half a cupful of paraffin into it to remove the gum of the old oil, and after a few minutes' run, oil with good suitable oil.

Keep your machine properly oiled, take care of it, and use it properly and you will find it the miner's most useful tool, and one that will last for years with very trifling repairs.

The introduction of rock drills into mines is not always accomplished without some difficulty and resistance from the miners themselves, who fancy that they will be thrown out of employment when the machines are set to work. I met with an experience of this kind when installing a drilling outfit in a mine in the South of France. The miners were so much against the introduction of machine work, that the drills were set to work under police protection, but notwithstanding all our precautions the first man who undertook to run one was assassinated, and the roof of the underground manager's house was destroyed by dynamite.

SPECIFICATION OF A COMPLETE PLANT OF MINING MACHINERY FOR OPERATING SIX OF SIZE "D" (3-IN. CYLINDER) ROCK DRILLS OF THE INGERSOLL-SERGEANT TYPE BY COMPRESSED AIR.

Drills, etc.	$	$	Shipping Weight.
Six standard mining drills, size "D" (3-in. cylinder), complete with valves and wrenches (unmounted), $275 each	1,650		
Six new style double screw tunnel columns, complete with arms and clamps, $60 each	360		
(Price of shaft bars, $50 each; tripods with weights, $50 each.)			
Six sets of fitted drill steels for drilling holes up to 10 ft. in depth, $16 per set	96		
Six lengths (50 ft. each) 1-in. rock drill air hose with couplings attached, $29 per length	174		
One set of blacksmith's tools for sharpening drill bits	10		
Total for drill outfit		2,290	4,287 lb.
Air Compressor, etc.			
One of standard class "A" straight line air compressors, of piston inlet cold air pattern, size "C O," cylinder 16 in. diameter, stroke 18 in.. Complete as specified, provided with improved water circulating jacketed cylinder and heads, automatic and adjustable regulator with unloading device for air and steam. Capacity of compressor sufficient to run seven of size "D" (3-in. cylinder) rock drills	2,500		
One steel air receiver, diameter 42 in., length 120 in.; furnished complete with gauges, safety-valve, and fittings	222		

Air Compressor, etc. (continued).	$	$	Shipping Weight.
One 70 horse-power horizontal tubular boiler of arch front pattern, complete with stack, grates, gauges, rollers, brackets, and all fittings, including injector, complete, ready to fire, except brickwork	1,344		
(Price of a portable boiler, 70 horse-power, complete, with injector, ready to fire, $1,305.) Locomotive water front on skids.			
Estimated cost of pipes, valves, and fittings to connect boiler with air compressor and air compressor with receiver .	95		
Total for compressor outfit . . .		4,161	28,800 lb.
Cost of complete plant . . .		6,451	
500 ft. of 4-in. air pipe for conveying air from the receiver to mine (price subject to market change), about 35 cents per foot	175		
Valves and fittings for pipe line, about	75	250	5,500 lb.
Total . . . . say £1,340 =		6,701	38,587 lb.

Skilled men can be furnished to superintend the erection of this machinery, and to instruct others in its operation.

All material delivered f. o. b. cars or boat in New York.

CHAPTER IX.

BORING MACHINERY.

Hand Boring by Percussion—The Surface Arrangements—Tools—Rate of Boring—Cost—Cost of Tools—Hand-power Diamond Prospecting Drill—Capabilities and Cost—The Diamond Drill—Description—Surface Arrangements—Details—Rate of Boring—Cost of Boring—Specification of Drill, and Accessories and Cost—The Sullivan Prospecting Core Drill—Sullivan Electric Drill—Cost of Boring with Sullivan Drills—Setting Diamond Drill Bits.

Hand Boring Machinery.—The geologist by his scientific theories cannot always persuade a body of men to risk their capital in the sinking of shafts, in order to prove the existence of mineral wealth under a property. They often, and rightly, prefer to have some tangible evidence, and this can only be obtained by boring either by means of percussion acting through rods with a chisel point or by the rotation of a cutting head or crown in which diamonds are set.

The old-fashioned percussion method is now rarely used for prospecting purposes, as though a simple and effective method of making a hole, it has the great inconvenience of pounding up the strata bored through to the state of slime, so that it is impossible to estimate their value with exactness, or to obtain from the sludge brought up any precise information as to the dip thickness of the beds and other matters of importance.

Before proceeding to describe the Diamond drill, which has practically for mining purposes superseded hand-power drilling by means of rigid rods, I will briefly describe the tools used in the older method. The appliances used may be divided into the headgear, which is erected on the surface and provided with a winch for withdrawing the rods. The rods, which are of iron, are 1 in. square, and from 6 to 10 ft. long, with a screw at one end and a socket at the other; and lastly, the cutting and extracting tools, which are fitted as required to the lower end of the rods.

The headgear consists of a simple framework of wood, with a pulley at the top, and is sometimes in oil regions called a derrick. The height of the pulley from the ground should be a multiple of the length of a single rod, and the greater the height the less time and trouble

will be required for lifting the rods from the bore hole. In practice it is usually from 45 to 50 ft., and this height is sometimes increased by sinking a small pit, as shown in fig. 134, which represents a simple arrangement suitable for comparatively shallow holes. A is a spring pole which relieves the men of the weight of the rods, and which for

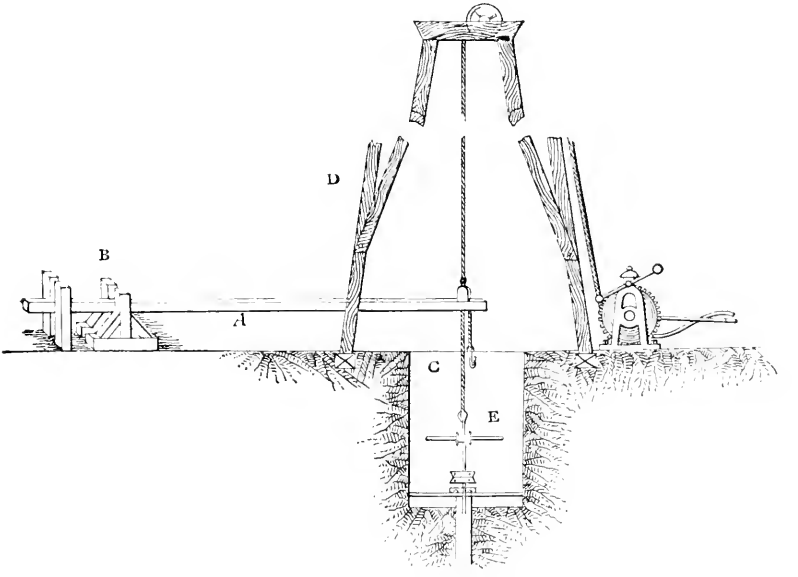


FIG. 134.—HEADGEAR AND GENERAL ARRANGEMENT FOR A BOREHOLE.

depths of over 50 yds., may be conveniently replaced by a lever of Memel fir 10 or 12 ft. long, as shown in fig. 134, the fulcrum being at 18 in. or 2 ft. from the end. The rods are attached to the spring pole or lever by means of a short length of rope between the hook at the extremity and the brace head (E). The brace head is a piece of oak

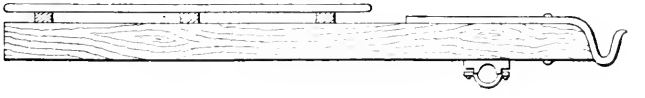


FIG. 135.—LEVER FOR BORING.

or ash, 3 ft. long and 3 in. diameter in the centre, tapering off to both ends, passing through an eye in a short length of rod, which can be screwed into the socket of the boring rod, and hung from the lever above. A man stands at each end of the brace head, and, aided by the spring pole, lifts the rods, at the same time turning them partly round. The fall of the rods strikes the blow which drives the cutting chisel into the rock. For the first few yards the assistance of the

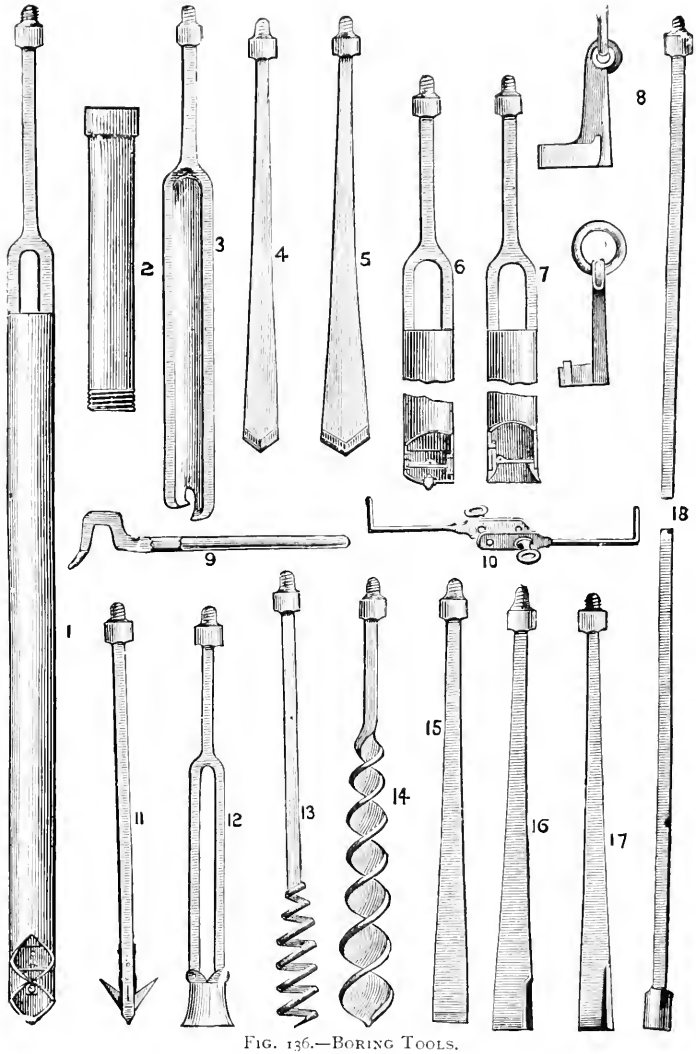


FIG. 136.—BORING TOOLS.

List of Boring Tools in fig. 136.

1. Shoe-nose shell with valve for bringing up loose stuff.
2. Wrought iron screwed well bore pipes.
3. Auger for clay and stiff soil.
4 and 5. V-nose chisels for hard ground.
6. Shell-auger with valve for loose and wet soil.
7. Bell-shell with valve for loose gravel.
8. Lifting dog for raising rods.
9. Pair of rod-wrenches for screwing and unscrewing rods.
10. Levers from turning rods.
11. Spring dart for drawing pipes in bore-holes.
12. Bell-box for bringing up broken bits
13. Spiral worm for extracting broken rods.
14. Worm auger for loosening stuff in bore-holes.
15. Square-nose chisel.
16. S-nose chisel for hard strata.
17. T-nose chisel for hard strata.
18. Rods with screw joints in 5- and 10-ft lengths.

spring pole is not needed, as the men can easily lift the rods if they are working in rock. The drift and gravel which usually overlies the rock at the surface is bored through by means of the shells and augers shown in numbers 1, 3, 6, 7, of fig. 136, and the hole is lined with tubing in order to prevent the sides running in.

When owing to the depth it becomes necessary to use the lever, two or more men are put to press down its extremity, and so raise the rods, while another man at the brace head turns them partly round; the lever is then suddenly let go, and the blow communicated through the rods to the cutting chisels causes it to penetrate into the rocks.

The boring tools used are shown in fig. 136.

From time to time, as the depth increases, the rods are withdrawn, and the sands pump or sludger (No. 1, fig. 136) is lowered into the hole in order to remove the rock chippings made by the boring tool. The sludger is an iron cylinder of a slightly less diameter than the bore hole, fitted with a valve at the bottom. It is lowered into the hole at the end of a rope, and is pumped backwards and forwards until full of the *débris*, which cannot escape because of the valve, and is then hauled to the surface. The contents of the sludge pump indicate roughly the nature of the rock passed through, and the length of the rods gives the depth.

The rate of boring decreases as the depth increases, owing to the time occupied in withdrawing the rods and effecting the necessary changes and clearances. For boring through the comparatively soft sandstone strata above the coal measures, Mr. G. C. Greenwell gives the following scale of charges, the master-borer who contracts for the work finding all the labour and material: for the 1st five fathoms, 7*s.* 6*d.* per fathom of 6ft.; for the 2nd five fathoms, 15*s.* 0*d.* per fathom of 6 ft.; for the 3rd five fathoms, £1 2*s.* 6*d.* per fathom of 6 ft., and so on in arithmetical progression, advancing 7*s.* 6*d.* per fathom for each additional five fathoms in depth.

The strata met with in metalliferous mining are, however, much harder, and consequently the cost of hand boring will in all probability be double the amounts above given.

The cost of a set of boring tools with 1-in. rods for a 100 ft. deep is approximately £45. The rods are 10 ft. long, and cost £1 5*s.* each, so that a set of tools for depths up to 300 ft. will cost the same as the above *plus* the cost of the additional lengths of rods required.

Hand-power Prospecting Drill.—The ordinary form of drill used for making bore holes, as described on page 197, labours under the disadvantages not only of being slow and cumbrous, but also of churning up the rock samples into slimes in the bore hole, so that when they are withdrawn for examination they are in the state of mud,

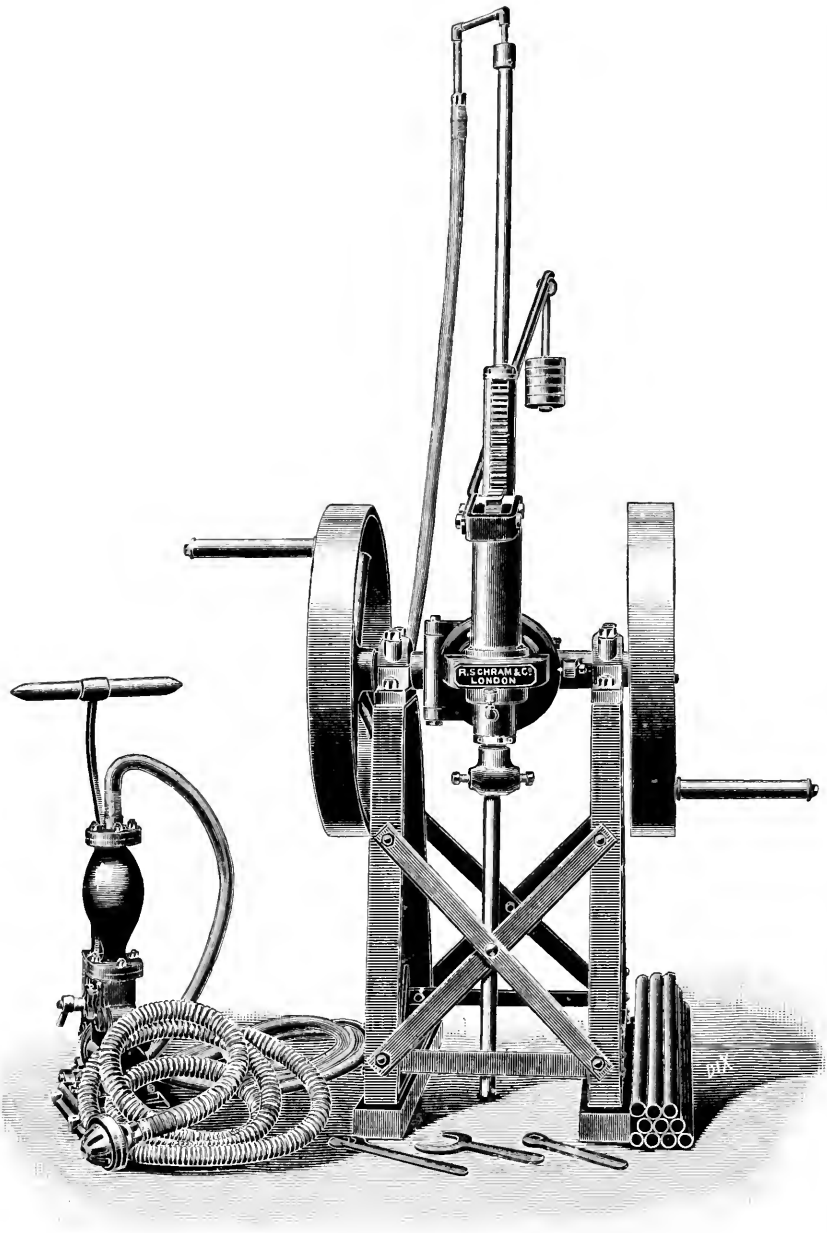


Fig. 137.—Diamond Prospecting Drill arranged for Vertical Holes.

and give only a roughly approximate idea of the nature of the rock passed through. With the Diamond drill, however, a solid core is withdrawn of the actual rock penetrated, and this gives not only the appearance of the strata, with its distinctive markings of the dip and thickness of the bed, but permits of a reliable sample being taken from which the value of the reef or lode may be accurately obtained.

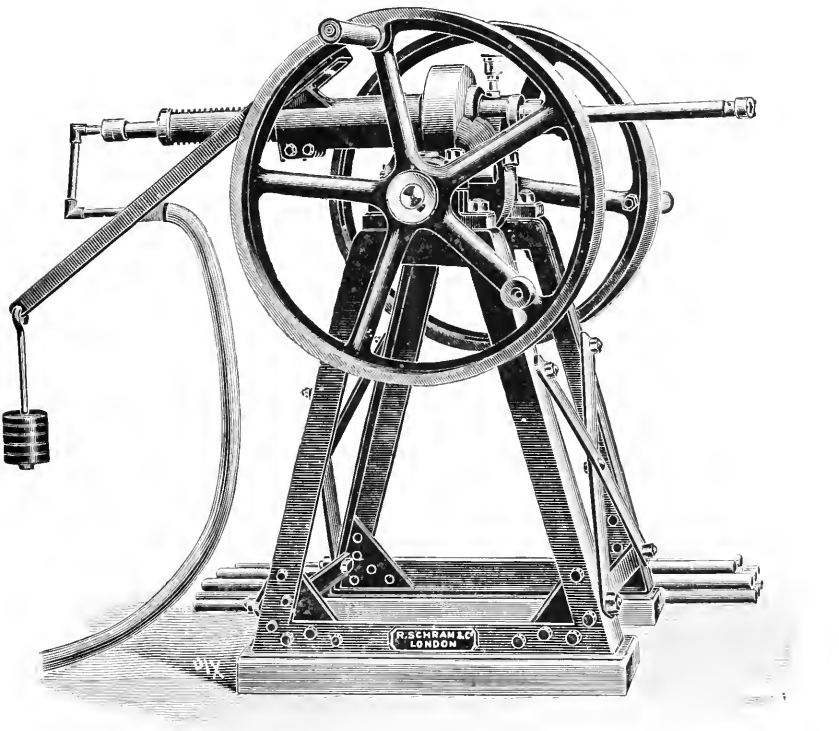


FIG. 138.—DIAMOND PROSPECTING DRILL ARRANGED FOR HORIZONTAL HOLES.

For prospecting purposes the Diamond drill is arranged in the manner shown in fig. 137 and is suitable for boring holes at any angle up to a depth of 300 ft. and $1\frac{3}{8}$ in. diameter, bringing out a core of $\frac{7}{8}$ in.

The boring rods, which are hollow, are revolved by the hand gearing, worked by two men, as shown; the third man is working a pump and forcing a supply of water down inside the rods, which keeps the boring head cool and cleans away the dust. Pressure is put on the rods by means of a weighted lever, the number of weights being lessened as the depth of the hole increases. The cores brought up are in lengths

of 2 ft., and are $\frac{7}{8}$ in. diameter; the drill will also bore horizontal holes for proving lodes or for tapping water when approaching old workings.

This machine, which is manufactured by Messrs. Schram & Co., of London, is of extremely simple construction, and can easily be taken in pieces for transport in out-of-the-way places, no piece being heavier than can be easily handled. By loosening eight bolts it is separated into four parts for removal.

It is particularly adapted for use with native labour. A few minutes' study of the explicit working instructions, sent with each machine, would render any man capable of operating the machine with good effect.

It is strongly made to resist rough usage, and all working parts are enclosed in a cast iron chamber; thoroughly protecting them from grit and damage.

The machine is so arranged that it can be driven by belt from a portable steam or petroleum engine if required—all that is necessary to effect the change being the removal of the handle. It can also be driven by electromotor or bullock gear.

As the boring descends and the feed of the machine reaches its lowest point, it is again raised by a simple mechanical contrivance, which can be performed in less than one minute; thereby practically involving no loss of time.

When it is required to raise the rods from the bore hole (to withdraw the "core," or for any other reason), the rods are uncoupled *between the machine and the bore hole*. The centre guide of the machine, being hinged, can then be swung back, leaving a free passage for the boring rods. By this method it is unnecessary to in any way disturb the rod passing through the machine; this is left in the machine, with the water-hose attachment intact, ready to be again coupled up when boring is resumed.

The rods are raised by the special rod hoister, which forms part of the equipment. This ingenious device enables the rods to be lifted with the smallest possible effort, and can be used either in conjunction with the machine or apart from it. The work of fixing it occupies only a few seconds.

The following is a complete specification of the outfit supplied with each machine:

1 Sector rod grip, for raising or lowering rods.
6 Spare unset crowns.
2 Core barrels.
2 Core breakers.
3 Core lifters.
1 Drill rod hoister, with improved ball clip.
2 Water swivels.
1 Water pump complete.
1 Press for plunger leathers.

1 Feed water strainer.
1 Suction hose 15 ft. long, with brass connections.
1 Delivery hose 30 ,, ,, ,, ,, ,,
1 Weight suspender.
10 Weights.
3 Pairs tongs for rods.
1 Crown chuck for vice.
1 Set diamond-setting tools.
6 Drill bits.
1 Box cement.
1 Bit brace and 2 chucks.
1 Drill support.
1 Bench vice.
1 Hand vice.
6 Assorted files
2 Pairs callipers.
4 Tommy keys.
1 Hammer.
1 Screw-hammer.
1 Oil Feeder.
1 Hack saw and 2 blades.

The prices of machines of this class vary with the price of material and diamonds, but generally speaking will be found to be as follows :

Machine complete with 2 flywheels hoisting gear.
Outfit of tools as per list already given, 2 core.
Barrels—one crown set with best black diamonds.
And 200 ft. boring rods and couplings. } £190 0 0.

Extra spare crowns set with the best black diamonds cost about £35 per crown, and the boring rods about £10 per 100 ft.

I have used machines of this type for exploration work underground with great success. Very little skill is required in their use and they can be entrusted to the care of an experienced miner. The vital and costly point is the diamond crown and as the preparation and care of this is practically the same for small as large size machines, I will refer the reader to page 214, where they will find instructions for the setting of diamond drill bits as used in the Sullivan power machines.

Messrs. Schram & Co. have recently made an improvement to this machine, adding a pair of small cylinders for use where air pressure is available instead of hand labour. Greatly increased speed is thus obtained without in any way affecting the handiness and portability of the drill.

The Diamond Rock Drill.—The full-sized Diamond drill (Appleby & Beaumont's patent) is shown in fig. 139, and is capable of putting down holes of 16 in. diameter to depths of more than 2000 ft., bringing out solid cores up to 30 ft. long, weighing more than 3 tons, giving a perfect section of the strata passed through, as well as an absolute sample of their mineral contents.

The framework of the drill is built of steel girders, and consists of a strong tripod mounted on horizontal girders, provided with all the appliances required to rotate the drill, to counter-weight the rods, and give a uniform pressure on the cutting-head, to manipulate the boring rods, and give the variable supply of water required for forcing to the

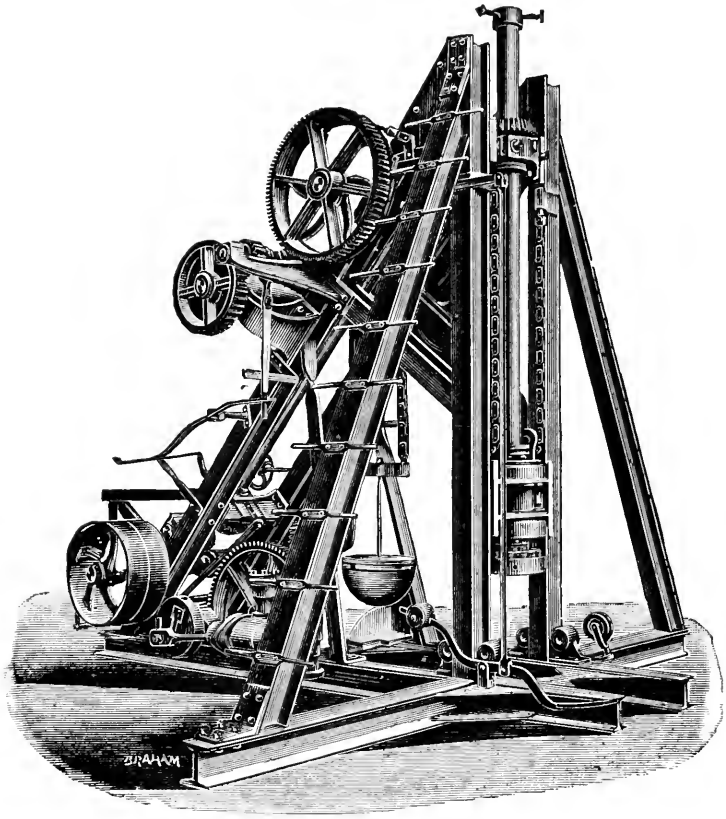


Fig. 139.—The Diamond Rock Drill.

surface the small particles of rock, resembling sand, which have been cut away by the drill in its downward progress.

The power is derived from a 10 horse-power portable engine, transmitted by means of belting and gearing. Over the machine a set of sheer legs are erected as high as possible, with a pulley exactly over the bore hole. By means of a chain connected to the hoisting gear on the drill and passing over this pulley, the boring rods can be lifted out in lengths of three or four at a time, thus saving much time in unscrewing and recoupling the rods. For very deep borings of large

diameter a substantial derrick must be erected, as the weight of rods and cores may amount to 10 tons or over. A lean-to shed protects the engine and drill from the inclemency of the weather.

The boring rods are made of solid drawn steel tubes with screwed flush joints, and are caused to rotate by being clipped in a universal chuck to a revolving quill, which has a stroke of 6 ft., and works in the vertical slides attached to the upright side-frames of the machines. The pump is connected to the top of the boring rods by means of a flexible tube. The weight of the rods is counterbalanced so that an even pressure is maintained on the boring crown.

The crown, or boring head, as usually made, is a short length of tube about the diameter of the hole required. Across the edge of it a few grooves are cut, in order to enable the water to pass under it freely as the boring proceeds.

The cutting edge of the crown is formed of nine black diamonds, commonly called carbonates. Three of these are fixed in the outer edge, three on the base, and three on the inside of the crown. Large holes requires a greater number. The diamonds set on the outer edge cut the path of the drill in its forward progress, while those on the other two faces enlarge the cavity, and so by abrasion cut an annular groove and leave a solid core in the centre, which fills the inside of the core tube.

The crown is screwed on to the core tube, and this latter for hard rock has a length of about 20 ft. The core tube is of a slightly less exterior diameter than that of the crown, and may be of much greater diameter than that of the boring rods which are screwed into it. The boring rods are hollow, and, when at work, a constant current of water is being forced down them in order to keep the crown cool and clear away the borings, which are carried up to the surface as fine sand.

The rods, and consequently the boring crown, revolve at the rate of about 250 revolutions per minute, and cut their way through the hardest rock at a rate varying from 2 in. to 8 in. per minute.

When a certain depth has been bored, varying according to the strata and the length of the core tube, the core clip is used for detaching the solid portion left standing within the annular groove cut by the crown, and the core is then raised to the surface. These cores are stored for reference, being accurately numbered and kept under lock and key, in order that the information thus gained may be known only to duly authorised persons.

The diamonds used are different to the gems, and are black in colour. They are supplied from certain mines in the district of Bahia, Brazil, and are not found of the same quality in any other diamond fields. They are fitted into holes prepared to receive them in the crown, and the metal is then drawn up around them, by means of a punch until only a very small portion of the stone projects beyond the steel ring.

Two varieties of diamonds are used—the "bort" and the "carbons." The bort is the real diamond, which, owing to its imperfections, cannot be used as a gem. It is nearly globular in shape, and is usually set on the outside edge of the crown. The carbon, as mentioned above, is a black stone of varying shape, and is sharp-edged.

The bort is much harder and dearer, the price being about 42*s.* per carat. The carbons cost about 26*s.* per carat.

The loss on the crown from the act of drilling half a mile is very slight, but the diamonds are apt to get broken from other causes. The average life of a setting, taking accidents into account, may be taken at from six to eight weeks, while the speed of boring varies according to the nature of the work, from, say 8 ft. per day in quartz or granite, to 10ft. per day of twelve hours in sandstone and slate.

The bore holes may be wholly or partly lined with tubes, in order to prevent the hole from being choked.

As a comparison of the rate of boring by means of rigid rods with that of the diamond drill, it may be stated that a bore hole made by the old method near Berlin took four and a half years for a depth of 4172 ft.; while a diamond bore hole near Lubthein, in Mecklenburg, was put down to a depth of 4000 ft., and completed in six months. The whole of the cores for this distance were obtained, and one was a fine specimen of rock salt over 20 ft. long.

The following is a complete specification of the outfit necessary for a machine, ready for work, for a hole 2000 ft. deep:

Boring machine, as shown in the illustration (about £395).
Portable engine of 10 horse-power.
2 straps for same.
6 1¼-in. flexible hoses.
3 pairs of unions.
2 water unions.
153 ft. of ¾-in. chain.
1 18-in. top sheave, with spindle and bearings.
2000 ft. of steel boring rods and joints.
300 ft. of 6-in. steel lining tubes, with steel joints.
400 ,, 5 ,, ,, ,, ,,
600 ,, 4 ,, ,, ,, ,,
800 ,, 3 ,, ,, ,, ,,
Special connectors—6 in. to 5 in., 5 in. to 4 in., 4 in. to 3 in.
6-in. to 3-in. steel driving shoes.
2 15-ft. core tubes.
2 special connectors of boring rod to core tubes.
2 ,, ,, of rods to 3-in. tubes.
2 6-in. boring crowns
2 5 ,, ,, ,,
2 4 ,, ,, ,,
2 3 ,, ,, ,,
4 2 ,, ,, ,,
} unset.

4 core clips.
2 6-ton hydraulic jacks.
1 3-ton set of blocks and falls.
2 lifting-swivels for rods.
1 set of eccentric clips.
4 patent rods tongs.
2 ,, tongs for 3-in. tubes.
2 ,, ,, ,, 4 ,, ,,
2 ,, ,, ,, 5 ,, ,,
2 ,, ,, ,, 6 ,, ,,
1 complete set of diamond setting tools in lock-up box.
1 5-in. parallel vice.
1 complete set of spanners.
2 patent shifting wrenches.
1 1-gallon oil-can and 2 oil-feeders.
1 set of stoking tools.
1 set of square valves for the pumps.
1 spare set of pinions in steel.
About 200 carats of carbonates or black diamonds.

This complete machine, engine, and outfit, will cost about £1400 exclusive of the carbonates, which vary considerably in value, and can only be quoted for from week to week. The price is about 42*s.* per carat.

The Sullivan Diamond Prospecting Core Drill.—As is the case with all machinery there is a continuous process of development and improvement, and in this drill which may be worked by steam, air or electricity, we have the embodiment of the latest ideas, the result of much observation, experience, and practical work.

Each machine, except in the case of the smaller sizes, consists of three parts—the engines, the hoisting, and the feed apparatus. These parts, although comprised in one machine, are yet distinct, and each can be operated independently of the others. They are mounted on a cast iron base plate, which rests on a bolted and braced hardwood frame. The base plate slides back and forth on ways on the frame, moved by a hand lever working in a rack on the frame. By moving the drill back in this way it is got out of the way of the rods while pulling up and lowering the rods, without the danger involved in the use of the "hinge joint." These arrangements are all shown in fig. 140. The engines are designed especially for these machines, with a view to simplicity, compactness, and economy. They are vertical, two in number, set quartering, and can be driven by steam or compressed air. Their special feature is in the proportioning and adjustment of the valves, which ride upon each other between the cylinders, interact on each other in admitting and cutting off the steam, and are thereby balanced. This arrangement allows great compactness of the engines, an unusually quick opening and closing of the cylinder ports, and produces a correct

distribution of steam for economy and smooth running. These engines are provided with a relief drip valve, by which all water can be drained

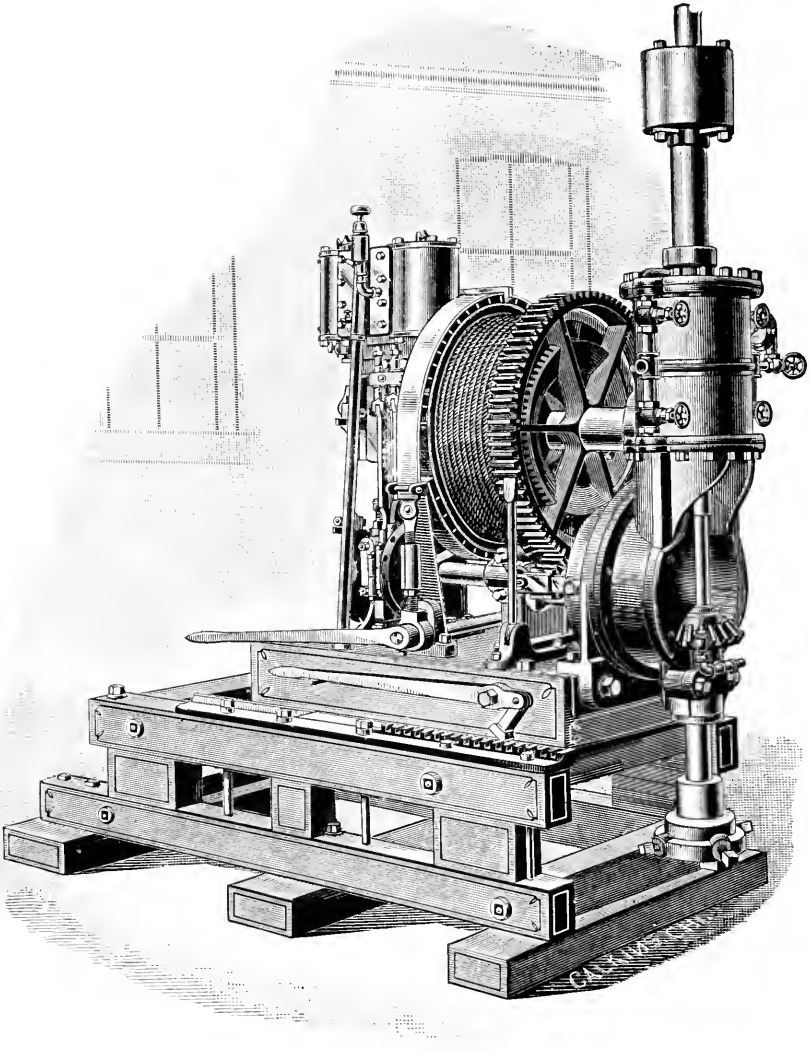


FIG. 140.—THE SULLIVAN DRILL.

from the steam pipes without entering the steam chest or cylinder, and with petcocks for draining the latter after steam is admitted to them.

The "E" and "S" drills are driven by single engines, well balanced and adapted to steam or compressed air.

The wearing parts of all the engines are few, and provided with ample means of lubrication and adjustment, so that repairs are not frequent. When necessary they can be made by any intelligent engineer or machinist; the drill runner, with a portable forge and the tools usually found in a drill outfit, can make all ordinary repairs.

The hoisting apparatus provided in the larger machines consists of an iron drum, wound with wire rope, and with suitable combinations of gearing for hoisting the full weight of the rods from any ordinary depth without the necessity of using double blocks. The drum is controlled by means of a powerful wood-lined brake, operated by a hand lever and screw or cam, and adjustable for wear. The hoisting gears are disconnected while not in use for hoisting, to avoid unnecessary wear. In the "M" Hand Drill and the "E" Drill, for underground prospecting, the rods are raised by hand-power, with rope and blocks. Also with the "E" Drill, they may be hoisted by steam power by means of a spool on the end of the engine shaft.

For the advance or "feed" of the drilling bit, the single cylinder hydraulic piston feed is used on all Sullivan Drills, except in case of the "E," "M," "R," "RS," and "S" Drills, where friction feed is used.

With the hydraulic cylinder the feed is not limited to three or four speeds, as in the case of the positive gear-fed drills, but can be adjusted to any degree of nicety necessary to secure the best results in speed and accuracy. Referring to the sectional view of the feed apparatus (fig. 141), it will be seen that its arrangement and operation are as follows:

To the upper end of the piston rod (C) is screwed the thrust plate (G) through which pass three studs screwed into another thrust plate (H). Between the thrust plates are two sets of friction ball roller bearings, one set on each side of the

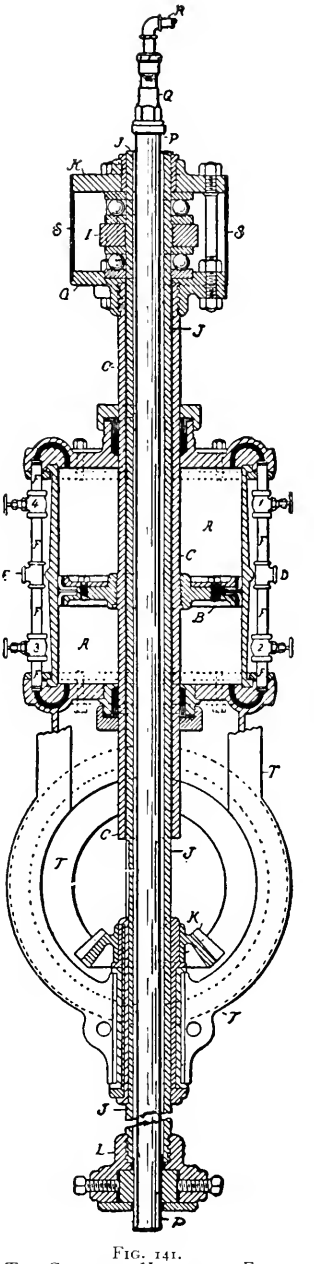


FIG. 141.
THE SULLIVAN HYDRAULIC FEED.

collar (I) on the drive rod (J). This collar transmits the vertical motion of the hydraulic piston to the drilling bit; for as the piston and piston rod descend they carry with them the two thrust plates (G and H), and the two roller bearings with the collar (I) between them. The collar is screwed fast to the drive rod (J) and rotates with it, the rod being driven by the mitre gear (K) and a similar mitre gear on the engine shaft. Thus the piston rod and drive rod descend together, the latter rotating within the former.

A long line of hollow drill rods, made up of 5-ft. or 10-ft. lengths screwed together, extends from the diamond bit at the bottom of the hole up to the drill passing through the drive rod (J), and held up and rotated by means of a chuck (L) screwed to the bottom of the drive rod. Therefore as the engine runs, turning the mitre gear and the drive rod, the latter rotates within the hydraulic piston rod and descends with it, sliding through the mitre gear and carrying with it the chuck, drill rods, and drilling bit. Thus by admitting water under pressure to one side or other of the hydraulic piston, and releasing an equal amount from the opposite side, the piston can be moved either up or down, the movement being called the "feed." The operator can thus by the simple adjustment of the inlet water valves vary the feed at pleasure, and instantaneously change it to suit the changing hardness of the rock being bored through, and is enabled to use his skill and judgment to secure the most rapid and satisfactory progress.

The fact that the feed apparatus is entirely independent of the engines, enables the feed to be increased, diminished, or reversed without loss of time. In short, the hydraulic feed is controlled by a constant pressure rather than by a constant rate of advance, and this pressure is under absolute control and can be varied indefinitely to suit the danger in the rocks bored through, with a consequent decreased strain upon the diamonds. Thus the hydraulic feed avoids the shocks and jars and consequent danger of breaking or wrenching out diamonds when drilling in rocks of different degrees of hardness, none of which can be avoided in drills using the "positive" gear feed.

The construction of the hydraulic cylinder and piping is such that the water cannot escape from the bottom of the cylinder faster than it enters at the top. Hence the lower part of the cylinder is *always full of water*; and, in case a cavity is struck, the weight of the drill rods, hanging on the piston, is supported by this body of water, which is *incompressible* and *prevents entirely the dropping of the rods*, and the hydraulic feed continues downward as regularly as in drilling through hard rock.

By the use of a single cylinder, with drill rods passing through its centre, the line of pressure is always kept directly in the line of the drill rods, avoiding cross strains and reducing friction.

As the hydraulic feed just described is not applicable to the smaller machines, another form has been used in their design. It is a friction feed, not hitherto applied to diamond drills, which consists of a system of differential gearing, driven by *friction*, instead of being "positive." The driving power from drill spindle to countershaft is transmitted through leather washers on either side of the loose upper countershaft gear. In

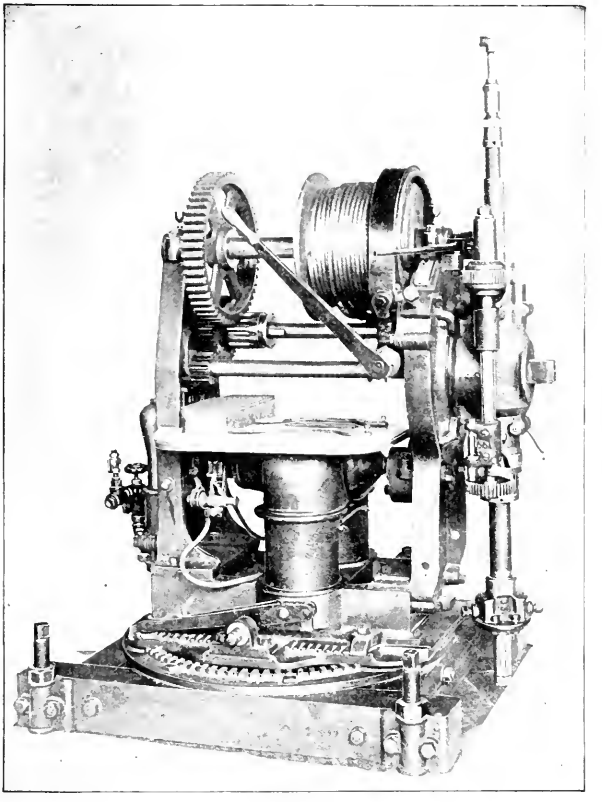


FIG. 142.—THE SULLIVAN ELECTRIC DRILL.

feeding, the gear and washers are pressed against a collar below them on the countershaft, by tightening a compression spring.

This spring is coiled in a sleeve, keyed to the countershaft above the upper gear. When the spring is compressed the countershaft revolves with the upper gear and washers at a speed determined by the amount of compression, the lower countershaft turning the feed nut gear, and as the amount of compression on the spring and consequently the friction of the washers can be increased or diminished at will; it follows that

the feed can be varied up to any limit fixed by the proportions of the feed gears.

These drills are made in sizes capable, in a hand prospecting drill, of boring a hole to a depth of 300 ft., to the large power drills capable of running a hole down to a depth of a mile or more and bringing up a solid core from that depth ; while the hole can be put down at any desired angle, or horizontally if desired for prospecting purposes in a mine.

The general arrangement of a Sullivan diamond prospecting core drill for drilling to a depth of 300 ft., using electricity as a motive power, is shown in fig. 142.

The motor for driving the drill is mounted on the same frame with the pump and hoisting drum, so that the drill, motor, and hoisting rig are part of the machine, which can be mounted on trucks for moving about the mine. The frame is provided with a swivel base, permitting holes to be drilled in any direction, as well as at any angle, without moving the machine.

The friction feed, already described, is used with this drill, as indeed with all the smaller sized Sullivan drills.

Switches, resistance box, etc., are provided for safety and convenience, and in order that the machine may be used in very wet mines, if necessary, great care is taken to insulate all parts likely to cause a ground connection.

The drills are usually wound for use with 110, 220, and 500 volt currents, but can be arranged to suit any desired voltage.

With regard to the rate of drilling with one of these electric drills at a mine in Aspen, Colorado, United States America, where the nature of the rock was a generally compact limestone, containing fractured and seamy gores, it is reported to have been $38\frac{1}{2}$ ft. per 24 hours, at a cost per foot of $ 0·81 which was afterwards reduced to $ 0·68 per foot including carbons losses.

The rate of drilling must of necessity depend upon the hardness, or otherwise of the rock passed through as will also the cost per foot ; and as an illustration I quote from a short paper read by Mr. J. J. Jordan before the London Institute of Mining and Metallurgy on April 17, 1901.

The subjoined figures refer to a series of six prospecting bore holes sunk in the Sombrerete Company's San Pedro mine, Fresnillo, Zacatecas, Mexico, in 1898.

The work was done by a Sullivan "C" drill, making a $1\frac{3}{4}$-in. hole and yielding a $1\frac{3}{16}$-in. core. The motive power was compressed air, and the water needed for washing out the hole and cooling the carbons was pumped from an adjacent mine drain. The bores were made from the 827-ft. level, and involved cutting 2 rises of 30 ft. clear to accommodate rods when lifted. At top of each rise was fixed a piece of 8 × 8-in. timber. with an eye-bolt for the hoisting sheave. The rock was hard

greyish-blue slate, with seams of quartz and heavy-spar carrying some argentiferous pyrites. At each set-up of the drill 3 holes were bored.

Details of Holes.

	A.	B.	C.	D.	E.	F.
Angle of inclination	36°	48°	56°	63°	64°	80°
Depth of hole	233 ft.	263 ft.	290 ft.	263 ft.	362 ft.	441 ft.
Length of core obtained	140 ft.	185 ft.	215 ft.	183 ft.	267 ft.	355 ft.
Percentage of core lost	40 %	30 %	26 %	30 %	26 %	20 %
Aggregate depth of holes bored					1852 ft.	
Average percentage of core lost					27·4 %	
Total time occupied, including all stoppages					3360 hours.	
Actual time drill was working					2480 ,,	
Time lost by stoppage of drill					320 ,,	
,, between shifts, in changing					560 ,,	
Percentage of time drill actually worked					73·8 %	
,, ,, lost					26·2 ,,	

Details of Cost.

	Total Cost.*			Cost per ft.	
	Mexican.				
	$ c.	£ s. d.		s.	d.
Labour, 2 drill runners	950	98 19 2		1	0·8
1 carbon setter	1550	161 9 2		1	9·0
2 helpers	336	35 0 0			4·5
	2836	295 8 4		3	2·3
Carbons, 21 carats @ 80 $	1680	175 0 0		1	10·6
Coal, 25 tons @ 22 $	550	57 6 3			7·4
Core-boxes, 30 @ 18	30	3 2 6			0·4
Bits, 26 @ 30 $ per doz.	65	6 15 5			0·9
Core-shells, 5 @ 6 $ 30	31 50	3 5 3			0·4
Core-springs, 12 @ 6 $ 30	75 60	7 17 5			1·0
Candles, 320 lb. @ 25 c.	80	8 6 8			1·1
Coal-oil, 80 gal. @ 1 $	80	8 6 8			1·1
Lubricating oil, 10 gal. @ 1 $	10	1 0 10			0·1
	2602 10	271 1 0		2	11·0
Carpenters' and smiths' work, repairs, etc.	25	2 12 1			0·3
Sundry extra labour	8	0 16 8			0·1
	33	3 8 9			0·4
Labour, cutting rises	400	41 13 4			5·5
Grand total	5871 10	611 11 5		6	7·2

* The Mexican dollar is computed at 2*s.* 1*d.*

The makers of the Sullivan Drills, Messrs. Fraser & Chalmers, send out the fullest instructions; and, as with these drills they have under contract bored over thirty-six miles of hole, they have had a large experience and have a staff of men especially skilled in the use of their machines.

The speed of drilling naturally varies with the hardness of the rock, and its cost with that of the cost of labour and material in the district and the facilities for obtaining them.

The construction, but more often the repair, of the diamond crowns or drill bits can be done on the spot by a skilled fitter and one who can be entrusted with the valuable stones. For this purpose the following instructions will be found useful.

Instructions for Setting Diamond Drill Bits.—The following instructions should be carefully studied and adhered to when setting bits for the diamond core drill:

For the "E" size bit six diamonds are used, and eight for the "A" size or larger. When the rock is extremely hard, two extra diamonds are set on the outside of the bit and directly opposite each other (fig. 143, Cut No. 6); these assist those on the outer edge of the face in retaining the diameter or size as first set. All bits should be set so as to be the same outside and inside diameter as the first one used.

The diamonds are set alternately (Cut No. 6); those on the outside cover the outer half of the face, and cut the outside clearance, while those on the inside cover the inner half of the face, and cut the inside clearance for the core to pass up freely.

After screwing the blank bit (Cut No. 1) into the setting block, the first step is to divide the bit into six or eight equal parts, according to the number of diamonds to be used, and mark with centre-punch (Cut No. 2) where they are to be placed. The breast drill and twist bits are then used to bore a horizontal hole in the side of the bit (Cut No. 2); each diamond should be studied separately and the holes bored in proportion to their size. As the outside diamonds can be more conveniently set than those on the inside, the largest should be selected for this purpose, and set first. Horizontal holes are used for the outside diamonds and vertical holes for those on the inside of the bit. After boring, the hole is chipped out by small chisels until the diamond fits very snugly in the metal (Cuts No. 3 and 4) and projects $\frac{1}{64}$ in. above the face, and the same distance from the outside and inside rim of the bit.

When the diamond is fitted in place and the proper measurement obtained, the metal is drawn up or closed around it (Cut No. 5); this is done by first making a cut with a blunt-edged chisel across the face of the bit about $\frac{1}{8}$ in. from each side of the diamond and all around it on the outer surface (Cut No. 5); then by using a dull-pointed chisel or caulking tool, the metal is gradually driven towards the diamond.

In order to get the diamond placed to the best advantage, it is often necessary to cut away more metal than it is possible to replace by driving up the original metal on the bit; in such cases, thin wedges, made of horse shoe nails, or copper wire hammered flat or wedge shape, should be used to fill up the space around the diamond before the caulking takes place. The setter should endeavour to place the diamond in such a position that it will have a sharp cutting edge on the face of the bit and at the same time leave a broad strong side or surface for the clearance on the outside of the bit (Cut No. 4), which will insure against much reduction in the size of the bit.

The diamond should be held in place by the third finger of the left hand, and the

chisel or caulking tool held between the thumb and first and second fingers. First drive up the metal on the face of the bit until it holds the diamond in its proper

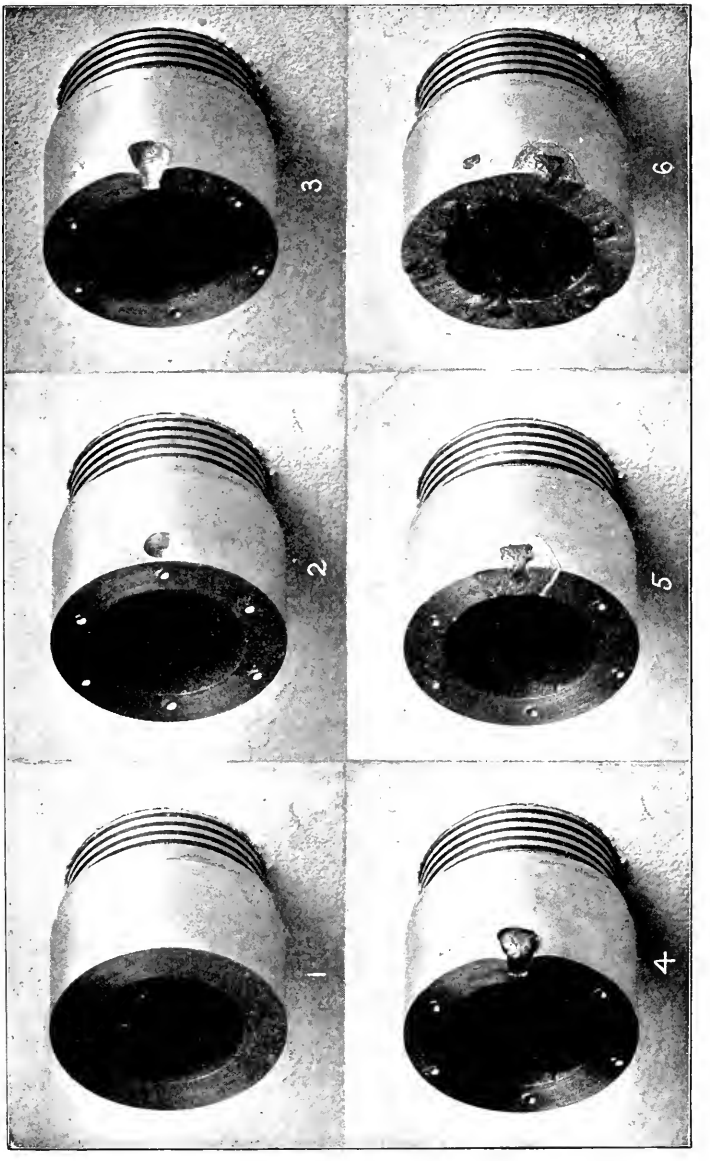


FIG. 143.—SETTING DIAMONDS IN DRILL BITS.

position; then the caulking on the sides can be done. Care should be taken that the diamond does not move from its proper position, thereby destroying the gauge or

measurement. When the metal begins to bear on the diamond, a finer pointed tool should be used, light blows struck, and the metal closed in carefully around it. It is possible to break the diamond by caulking the metal too tightly, and also by driving the metal to fill an opening near the corner of the diamond, while the metal may be pressing hard on it at another point ; it is, therefore, necessary to drive the metal so that it will be brought to press uniformly all around.

Whenever the drill is withdrawn from the hole, the bit should always be carefully examined, and if any of the diamonds are found to be loose or the metal worn away so as to leave some of them unprotected, the metal should be re-caulked around them. (By "re-caulking" we mean to close in the metal.) When the bit is so badly worn that the diamonds are greatly exposed, they should be cut out and reset in a new metal blank.

If, while drilling, some of the outside diamonds are broken, so that the size of the hole is reduced, when the next bit is introduced that portion of the hole bored after the diamonds were broken should be re-bored so as to be the full size of the standard bit, as any attempt to force the new bit down into the reduced hole, either by trying to turn the rods with tongs or otherwise, will be sure to destroy the outside diamonds.

To remove the diamonds from an old bit, make a cut across the face of the bit about $\frac{1}{8}$ in. from each side of the diamond with a hack saw or file ; then with a chisel drive the metal back and chip it away, until the diamond can be forced out by light taps of the hammer on a small copper rod.

The diamond-setting tools are as follows : One $3\frac{1}{4}$-in. jaw vice, with swiveled base, one breast drill, with five twist bits, size $\frac{1}{8}$ in. to $\frac{1}{4}$ in., each varying $\frac{1}{32}$ in. from the next, one set of 12 setting chisels and punches, one light hammer, one pair 6-in. dividers, one pair 6-in. inside calipers, one pair 6-in. outside calipers, one setting block or chuck, for holding the bit while setting.

CHAPTER X.

CONCENTRATION MACHINERY.

Selection of Concentration Process—Mill Tests without a Mill—Coarse Concentration—The Blake Crusher—The Dodge Crusher—The Gates Crusher—The Picking Table and Washing Trommel—Ore Feeders—Shaking Feed Screens.

As a general rule the ores of metalliferous minerals are not in such a rich state when they come from the mine as to admit of their being at once sent direct to market. They must be enriched by some means or another, so that the worthless gangue, or country rock, may be got rid of, thus increasing the quantity of metallic matter in the ore and avoiding the carriage of useless rock to the melting furnaces, which are frequently at long distances from the mine. The process of enriching the ores is termed concentration, and the successful methods of concentrating ores can be divided into two general systems:

1. *Coarse concentration*, in which the ore is crushed coarsely, divided into several classes or sizes and treated on various different concentrating machines, usually followed by slime dressing or fine concentration appliances.

2. *Fine concentration*, in which the ore is crushed finely and treated with or without classification on one style of concentrating machine.

A combination system is occasionally employed on some ores, in which the material is crushed finely but classified into two or more sizes, being treated on two styles of concentrating machines, or treated separately on machines of one style differently adjusted.

The choice of one or the other of the above systems should depend entirely on the nature of the ore to be treated, though too often the selection is based on chance, prejudice, or personal limited experience. The ores adapted to coarse concentration are those containing the mineral to be saved in large crystals, masses or seams, so that when broken in comparatively large pieces a good separation is effected between waste rock and valuable mineral. Many ores of lead, zinc, copper, and iron are of this character. The ores adapted to fine concentration, on the contrary, contain the valuable mineral in fine particles or crystals disseminated through the mass of the rock in such manner that a coarse crushing would leave the pieces of waste rock still impregnated with

mineral, and a finer crushing therefore essential. Ores of silver, gold, and tin are usually of this character, the silver ores frequently comprising also combinations of lead, copper, and zinc of secondary importance.

The machinery employed for the coarse concentration of ores consists of stone-breakers, picking tables, roller crushers, sizing trommels, jiggers, classifying apparatus, fine jiggers, and some form of buddle, table, or vanner for treatment of the slimes. The ore is crushed as little as possible, and every effort made to avoid the formation of sands and slimes.

For fine concentration, on the other hand, the ore is reduced at once to sand, and then concentrated by means of the same machinery as that employed for the classification and enriching of the sands and slimes made in coarse concentration. In the case of gold and silver ores, the precious metals are, if possible, when in a free state, extracted by means of amalgamation before concentration ; but most of the ores require both the processes. The following general rules as to the selection of a concentration process will be found of considerable utility.

The Selection of a Milling or Concentration Process.—The selection of the most profitable process and machinery for the treatment of a given ore is a matter of great importance in a mining enterprise; but as some ores are susceptible of successful working by more than one process—and in such cases local conditions must determine which method will yield the greatest profit—it is not possible to lay down exact rules covering all cases. The following notes will, however, serve as a guide in some instances, and in all as a general indication of the principles of the processes in common use, and conditions governing their application. Where there is any doubt working tests should be made.

As before stated, no law can be laid down for the determination of the most profitable process for a given ore; for where hard cash is in question, theories and practice must give way to exigencies of particular cases. Taking it for granted, however, for purposes of general deduction, that all the above-described processes are equally available, differing only among themselves in simplicity of execution, cost of plant and consumption of supplies, the following notes will indicate the process to be selected for the ores commonly met with.

If free gold can be panned out and no sulphides = free gold milling.

Free gold found, but also sulphides, which, on being panned out, after free gold is separated, assay sufficiently well to pay for treatment after = free gold milling, with vanning machines for tailings; chlorination, or smelting for product.

Free gold in small quantities, but much silver present in sulphides = roasting milling; or free gold milling, vanners and smelting; or copper plates, vanners and pans.

Chloride of silver ores, and decomposed silver vein outcrops, over 6 oz. per ton = free silver milling.

Silver ores consisting of part chloride or decomposed, and part silver-bearing sulphides = free silver milling, vanners and smelting; or, if grade of ore is high = roasting milling.

Silver ore with base metal sulphides, if low grade = fine concentration and smelting; if higher grade = roasting milling.

Low grade silver ores, with grey copper, tellurides, ruby, brittle, or native silver = fine concentration and smelting.

Heavy mineralised ores of lead, copper, zinc, often carrying silver = coarse concentration and smelting.

Lightly mineralised ores of lead, tin, copper, zinc = fine concentration and smelting.

Carbonate or oxide of lead or copper = smelting.

Solid galena ores = smelting, either after simple hand selection or hand selection and coarse concentration on rejected ore.

Metallic copper ores = stamping with coarse concentration and melting to ingot.

Antimony ores = hand-picking, coarse or fine concentration, and smelting for metal.

Zinc-blende and zinc-carbonates = coarse or fine concentration and reduction by a zinc-smelting process.

Tin ores = fine concentration, roasting, and smelting.

Copper pyrites, and copper = glance hand-picking, coarse, or fine concentration, partial roasting, and matting; or if on sea-board, shipment of selected and concentrated product to refineries; or if low grade, sometimes lixiviation for copper and silver.

Heavy iron pyrites, carrying gold = chlorination process; or roasting, and intermixture with smelting ores.

To determine if a given low grade silver or gold ore is adapted to fine concentration, the following simple test will suffice: Take a weighed quantity of average quality passed through a 40-mesh wire screen—not a selected sample, but such as will represent the average bulk of the ore to be treated—say 2 oz. or 4 oz., after having previously assayed the sample. Pan this weighed quantity carefully into a second pan, reserving the mineral concentrated. Pan back again from the second pan into the first, settling well each time, and add the concentrates each time to those first obtained. When no more fine mineral can thus be panned out, dry, weigh, and assay the total concentration obtained: assay the tailings left. A simple calculation will give the percentage of the assay value of the original ore obtained in the concentrations. The value of the concentrations per ton being determined, and the loss produced in the process, all the necessary details are at hand for deciding if fine concentration will prove profitable. In

skilful hands this test is a safe guide for practical work; while in hands not used to panning the results in practice will be better than those obtained in the experiment.

In all cases the sending of a bulk sample of a few tons, if possible, to the makers of the machinery is strongly recommended; and there are some manufacturers who will refuse to supply any machinery unless they have first of all experimented on a small cargo, and can thus confidently guarantee the success of their processes and machines.

Mill Tests Without a Mill.—A very close approximation of mill results in free milling gold ores may be made by amalgamation, thus:

Exercise great care in securing an average sample of the ore; pulverise 4 lb. of this sample to the fineness of the screens which would be used on the mortar of a mill in treating same (usually 30 to 60 mesh), being careful to see that no gold remains upon the meshes of the screens employed. Place the pulp in an iron or wedgewood mortar (preferably the latter) of about one gallon capacity, adding clean warm water enough to make a thin paste of the contents.

Pour about one ounce of clean quicksilver into an earthen or iron dish, and warm to ensure that all water is evaporated from it. Place a piece of freshly cut metallic sodium, about the size of a pea, on the end of a splinter of wood about a foot long, and drop it upon the quicksilver, keeping the person at a little distance to avoid injury from the flash of fire that may follow. After the sodium has disappeared, introduce the quicksilver so treated into the mortar and stir and grind the contents with the pestle for an hour, in which time the charge should be thoroughly amalgamated. Upon examination it will be found that the quicksilver is divided into minute globules all through the mass. Water may now be added freely to dilute the pulp, when the charge should be further stirred to settle the amalgam and quicksilver to the bottom. Carefully pour off the water and pan off the sands, using two gold pans for the purpose, repanning from one into the other, removing the quicksilver each time, until it is certain that no visible quicksilver has been lost. If the resultant globules of quicksilver are not inclined to unite into one mass, they may be made to do so by first drying them and then rubbing them with a piece of sodium held in the end of a glass tube.*

The quicksilver so collected will contain the free gold that was in the sample, and is now amalgam. Carefully wash away all dirt or sand,

* Metallic sodium must be kept in a bottle, tightly corked, and is best preserved by being covered with naphtha or benzine. It burns violently in contact with water, and must therefore be handled with care. Quicksilver treated with an excess of sodium will amalgamate clean, bright iron, and should be diluted with more quicksilver before use in amalgamating gold.

then squeeze out the excess of quicksilver through a piece of wet buckskin or chamois leather. Do not attempt to squeeze the amalgam hard, but leave a ball about the size of a pea to be retorted, the following being a good method: Procure a medium-sized potato, cut it in half, and hollow out a piece into a cup, with sides and bottom $\frac{1}{2}$ in thick. Make a dent upon an old shovel blade or similar thickness of clean sheet iron, place the amalgam in the dent and cover with the potato, being careful to make it fit snugly all around.

Heat very slowly over a forge of live coals, this will bake the potato fast to the iron and seal the retort; maintain a low heat for some minutes, then raise the heat gradually, but very slowly, until the iron is slightly red; maintain this heat for several minutes, then remove from the fire and allow to cool. Upon removing the potato from the iron, the gold will be found where the amalgam was put, and the quicksilver will be attached inside the cavity of the potato in the form of small globules. The gold should be treated with dilute nitric acid, dried and weighed. Multiplying the weight by 500 gives the weight of gold per ton of 2000 lb.

If it is desirable to make the test upon a larger quantity of ore, say with a 20 lb. sample, this may readily be done in five successive grindings, the amalgam being combined in one lot and retorted in one operation. In this case the weight of gold obtained would be one per cent. of free milling value per ton of 2000 lb. If the ore contains partly free gold and partly in association with sulphides of iron and arsenic, then the free gold is first of all to be separated and the remainder concentrated by panning and the concentrates assayed, as has already been described on page 219, for the determination of a low grade silver or gold ore.

In the following pages the process, first of coarse concentration and afterwards of fine, will be taken step by step, describing the machines which have met with acknowledged success, and the conditions under which they will work to the greatest advantage. Afterwards will be given the description of one or two typical mills, showing the arrangement of the machines and the plan adopted to make the whole process as much automatic as possible.

Machinery for Coarse Concentration.—*Rock-breakers.*—The first operation of smashing up the rough blocks of ore as they come from the mine is now almost universally done by means of rock-breakers of the well-known Blake type, which is illustrated in section in fig. 144. A is the main framing of cast iron; B is a false back, accurately planed and fixed to the frame (A), against which the jaw plate (c^1) is accurately bedded either by running in white metal or by the use of soft metal strips, the same mode being adopted in the case of the swinging jaw (c^3).

The jaw plates are reversible, so that, when the lower edge is worn, they can be readily turned round. The jaw plate (c^1) is held in its position by means of the wedge plate (c^5).

The swinging jaw (D) is accurately planed, and is rocked on the bearing (E) by means of the plunger (H) acting through the toggle plates (J K). The width between the jaws is regulated by means of the wedge (L), and the swinging jaw (D) is pulled back by the rubber buffer shown below the machine. P is one of two flywheels, and Q is the driving pulley, the speed at which the machine is driven being from 200 to 300 revolutions per minute. The size of the machine is based upon the width of the top jaw opening, which also shows the size of a block of stone which may be put in.

A jaw-breaker capable of crushing 10 tons per hour down to the

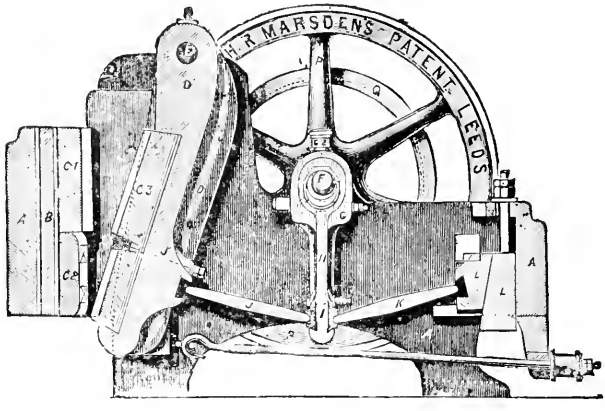


Fig. 144.—The Blake-Marsden Rock-breaker.

size of road metal would have a jaw opening of 20 in. by 10 in., and would require a power of 8 nominal horse-power, the total weight of the machine being 8½ tons. For export purpose and use in mountainous countries, these crushers are made in small pieces for easy transit on mules' backs, where no other mode of carriage is available.

These breakers are usually supplied with cubing jaws suitable for making macadam, but for finer crushing I have used jaw plates with a perfectly flat surface with good results, and no loss of grip by the jaw on the ore. These machines can be used either for dry or wet crushing, and are not liable to get out of order, the principal wearing parts being the jaw plates.

The Blake stone-breaker has been so improved in details that in its present form the Blake-Marsden stone-breaker (fig. 145), as it is now termed, only resembles the original machine by adherence to the

broad fundamental principles on which its construction was based. The stone-breaker is driven in the usual way by a pulley (Q) upon a crank (F) instead of an eccentric shaft. Upon this shaft a connecting rod (G) is attached, and at the lower end of the connecting rod is spindled one end of a solid crucible steel lever, the other end of which is fulcrumed to the main frame. As the connecting rod (G) lifts up and down, it actuates the lever (H) in such a manner that the toggles (J and K) give the necessary motion to the swinging jaw (D) for breaking or crushing the material under treatment. One of the great advantages of this machine lies in the fact of there being a false back (B) accurately planed and fixed to the frame (A) itself, against which the three fixed jaw faces (C^1, C^2, C^3) readily bed, thus avoiding any degree of concussion, and also providing a means whereby these faces can be renewed and

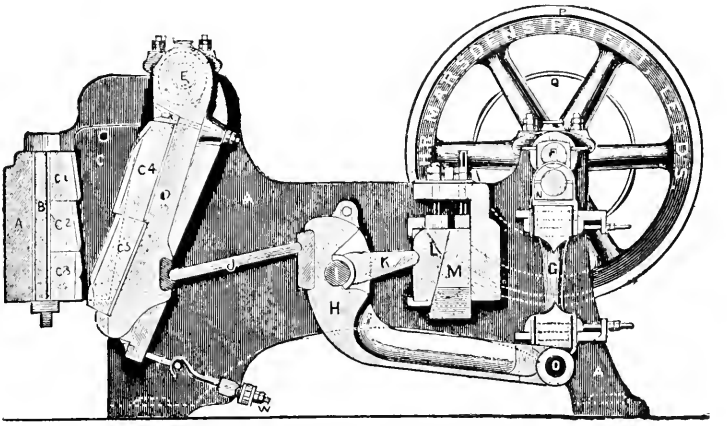


FIG. 145.—THE BLAKE-MARSDEN IMPROVED STONE-BREAKER.

reversed in position in a few minutes, at any time, without the use of white metal for running up. These faces are fitted with surface strips on the backs, which also facilitate a dead bearing. The swinging jaw (D) is accurately planed, and the wearing faces (C^4 and C^5) of this are fitted in the same manner as the others. This one advantage can hardly be over-estimated, as the full power of the engine is employed in the reduction of the material. The frictional parts in this machine are greatly reduced, especially the main crank-shaft (F), which has been lessened 1 in. in diameter in a medium machine. The adaptation of the parts is such as greatly to relieve the strain upon the machine, and the leverage gained has reduced the power required to drive by about one half. The whole of the shafts and axles are made of best hammered steel. The bearings are pillowed throughout with brass bushes, accurately bored. The toggle cushions are of solid crucible

cast steel. The motion obtained by the toggle and lever cushion gives an interrupted movement to the jaw to suit any kind of material; this also prevents clogging. For a certain portion of the revolution of the flywheel (P) the jaw is stationary; the result is a sudden blow by the jaw upon the material, exactly similar to that of a man hitting the stone with a hand hammer. The result, it is claimed, is a much better sample of road metal than it is possible to get by any other machine, and less waste in chippings. These machines are made in sizes varying from 4 in. by 2 in. up to 30 in. by 24 in. at the mouth, and these are the sizes of material each machine will take in. A further evidence of the little power this new type takes to drive is shown in the 8 in. by 6 in. being capable of being worked by hand power.

With regard to the power required to operate stone-breakers as well

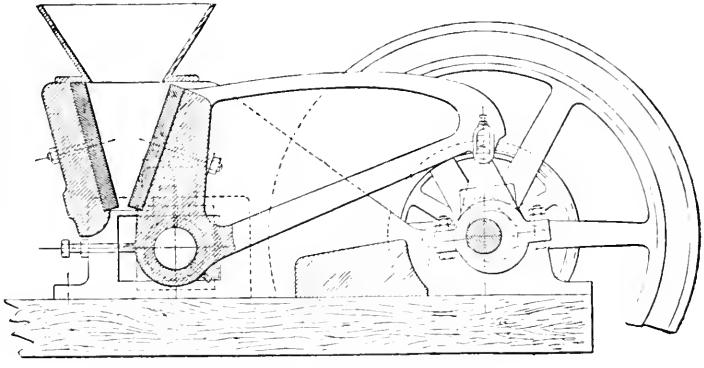


FIG. 146.—THE DODGE CRUSHER.

as other machines, it must be remembered that it is far more economical to use, say 9 horse-power, from a 12 or 15 horse-power engine than it would be from one of 9 or 10 horse-power. For other reasons also, it is always advisable to have an excess of power available, and not to run the motive power up to its utmost limit.

The Dodge Crusher.—A jaw-breaker of the well-known Blake type is not adapted to the crushing of ore down to, say, the size of nuts, owing to the movement of the lower part of the jaw being greater than that at the top, thus allowing a product of various sizes to pass through the opening during the stroke. In the Dodge crusher, which is illustrated in fig. 146, this movement is reversed, the lower part of the jaw remaining practically stationary, while the upper part is movable and does all the breaking. Consequently the ore must be reduced to a certain size before it can leave the machine, this size being determined by the distance at which the jaw plates have been set apart.

The action of the machine will be readily understood from the illustration. The lever is driven by an eccentric on the main shaft, and the jaw shaft rests in movable boxes; the size of the lower jaw opening being varied by means of packing blocks fixed on either side of the movable shaft boxes, which can be changed by loosening the screws.

For fine crushing, the packing blocks are put in the side nearest the eccentric or driving shaft; and for coarse crushing they are placed in front next to the screws. The machine, however, is not meant to be a fine crusher in the sense of pulverising. It works best when used for reducing down to the size of nuts, and for this purpose a No. 3 machine, having a jaw opening of 8 in. by 12 in., running at a speed of 220 per minute, is estimated to treat from 2 to 5 tons per hour, according to the nature of the material, and would require from 8 to 12 horse-power to accomplish this. The machine must therefore be considered as for doing the intermediate work between a stone-breaker and the stamps or rolls.

The Gates Rock-breaker.—The rock-breaking machines, built on the jaw or Blake principle, have deservedly come into favour with mining men all over the world, both for their simplicity of construction, efficiency, and durability. They have, however, now to compete with a rival machine based upon an entirely new principle, called the Gates rock-breaker, for which the makers claim that it will do double or treble the work, will break smaller, absorb one-third less power, and wear better than the jaw machines. A sectional perspective view of this machine is given in fig. 147, and a longitudinal section in fig. 148.

The main shaft (G) is of forged steel, is supported on the chilled iron octagon step (P) and held in the centre of the shell (Q) by the top (C). The chilled iron breaking head (F) has two soft iron rings cast into the centre of it, one flush with the top, and the other flush with the bottom. These rings are of sufficient width to leave a space between them the same length as the taper-planed octagon on the shaft, and the space between the rings is cored out octagon a little larger than the taper-planed octagon on the shaft. The shaft, above and below the octagon, is turned on a taper the same length as the width of the soft iron rings in the head, and these tapers, as also that of the planed octagon, all taper towards the top of the shaft. The rings in the head are bored out, the upper one to fit the taper on the shaft above the octagon, and the lower one the taper below it. The head is put on over the top of the shaft, and when it has been driven down to its bearings the octagon faces on the shaft, and in the head will come opposite each other. The space between them is run full of zinc, which keeps the head from turning on the shaft, and makes a smooth bearing against the octagon of the shaft. The rings are screwed down, thus securely fastening the head on the shaft; but it can be pulled off when

required, since the whole of the shaft inside the head tapers toward the top.

There are twelve chilled iron liners (E) placed inside the shell (Q), the space behind and between them being run up with zinc. These can be removed when required by first driving in the key liner (which has reverse bevels on its edges), by the use of a wrought iron or steel pin, through the hole in the shell (Q) at 2. There are three openings in the top (C) through which the material to be broken is thrown in all round the breaking head.

N and N represent two small square oil passages cored in the bottom plate 3, which convey the oil down to the space at Y. The shaft (G) can be raised to regulate the size of the opening at the lower end of the chilled iron head (F) and liners (E) by the screw (S). A gyrating motion is imparted to the shaft (G) by the brass eccentric box (D), which is securely attached to the bevel wheel (L), forming a long hub to the same. This eccentric box is babbitted on the inside and outside of the thickest part, as shown by the heavy black lines, and, as all the wear is on this side, can be readily rebabbitted, should it become necessary through loss of motion or throw. The outside of eccentric box (D) is turned to fit the bore of the bottom plate 3 in which it revolves; the inside is bored to fit the journal of the shaft (G), but is bored eccentrically, enough to crowd the shaft out of the centre just sufficient to produce a fracture or breaking of the material being operated upon between the chilled iron head (F) and liners (E). The shaft (G) is a loose fit in the eccentric box (D) and does not revolve except when there is no material between the breaking head and liners, in which case it revolves with the bevel wheel and eccentric box, owing to the slight friction the eccentric box causes in revolving around the journal of the shaft, but this ceases the moment any material is put between the breaking head and liners, as the resistance of the material overcomes the friction.

It will be seen that the closest point of contact between the breaking head and liners is always at that part of the head which is exactly opposite the thickest part of the eccentric box (D), and that as the eccentric box is revolved around the shaft the point of contact is constantly moving before the eccentric, so that when the eccentric box has made a full revolution around the shaft the point of contact has moved forward to every point around the liners (E). It will also be seen that the material is broken at the point at which the head and liners are in closest contact, and when the head has been moved to the point of contact opposite the material drops down a little, to be broken again when the head has been moved around to that point again, and when broken small enough drops down on to the inclined diaphragm and slides out through the opening in the

shell (Q Q). There being three openings in the top (C) through which the material is thrown in all around the breaking head (F) it will be seen that every time the eccentric box has made a full revolution the breaking head has acted upon every particle of material in the space between the breaking head and liners, and that there is not a moment it is not breaking the material at some point. The bandwheel (T U) is a loose fit on the shaft (X). The break pin hub (V) is keyed fast to the shaft (X) and has a hole in it through which is passed the break pin (W) into a hole in the hub of the bandwheel. The break pin is held in place by the set-screws in the break pin hub (V) and is of no more than sufficient strength to stand the strain necessary to break the material being acted upon, and should an accident occur (such as a piece of steel getting into the breaking surfaces), the strain would become so great upon the break pin that it would break off, and the bandwheel would revolve on the shaft (X) while the machine would stop until the article had been removed, and a new break pin put in. The loose collars (H and I) are to keep the dust out of the journal, and gyrate with the shaft (G).

THE FOLLOWING REFERENCE LETTERS APPLY BOTH TO FIG. 147 AND FIG. 148.

A—Is cap for keeping dirt out of journal or ball-joint, between quarter boxe (B B).
B—Are quarter boxes at journal at top of shaft (G).
C—Is top of breaker.
D—Is brass eccentric box, at bottom of shaft (G).
E—Are chilled iron concaves or liners.
F—Is chilled iron head.
G—Is main shaft forged steel.
H—Is collar fitted close around shaft (G), to keep dust and fine stone out of lower part of breaker.
I—Is collar fitted close around shaft (G), to keep dirt and dust out of journal at eccentric (D).
J—Is an oil hole through collar (I) where oil is poured into journal at eccentric (D).
K—Is a collar cast (solid) on hub of bevel wheel (L).
L—Is bevel wheel.
M—Is bevel pinion.
N—Is oil hole to let oil to bottom of journal at eccentric (D).
O—Is steel point in bottom of shaft (G).
P—Is chilled iron step under bottom of shaft (G).
Q—Is the shell.
R—Is jam nut on screw (S).
S—Is screw for raising or lowering shaft (G).
T—Is driving pulley.
U—Is flywheel.

V—Is break pin hub.
W—Is break pin.
X—Is countershaft.
Y—Is pipe through which old oil is drawn off and the journal at eccentric (D), *washed out with hot water.*
Z—Is screw collar to keep head (F) from working up.
2—Is hole in shell (Q) where key concave is driven in. This concave is not bevelled on its sides, and it, or one just like it, must be put back in the same place, as a bevelled concave cannot be driven in after once run in with zinc.
3—Is the cast iron bottom.
5 and 6—Is wood frame to which breaker is fitted.
7—Is the widest opening where broken stone is being discharged when head is breaking on other side.
10—Is boiler iron hopper.

The machine is oiled through the hole (J) in the loose collar (I), the oil finding its way down through the journals to the space (Y). By an ingenious arrangement of the oil passages (N)—of which there are four—in the base plate 3, the motion of the machine causes a constant circulation of the oil through the journals of the shaft and eccentric box. The old oil is drawn off through the pipe on the side of bottom plate 3, and by pouring hot water through the hole (J) in the loose collar (I) the journals are washed out, the dirt and water running out through the pipe.

The breaker is made in a variety of sizes from 00, which is a sampling machine for laboratory work, to No. 8, which weighs 89,000 lb., and is capable of crushing from 100 to 150 tons of rock per hour down to a $2\frac{1}{2}$ in. ring, for which purpose it would absorb from 125 to 150 indicated horse-power.

Picking Table and Washing Trommel.—After passing through the stone-breaker the mineral is roughly classified in a strong washing trommel, the holes in which may be $\frac{1}{2}$ in. diameter or greater, according to the class of mineral; the fine stuff which passes through goes on direct to the roller crushers, but the rougher stuff falls on to the picking table, as in fig. 149.

The washing trommel should be of exceptionally strong construction, and is best made of boiler plate, with holes drilled to suit the ore. It should be well supplied with a strong stream of clean water, sufficient to thoroughly cleanse the ore. In the case of argillaceous ores, which are liable to form into clayey balls, a special washing trommel is used, which is referred to in the description of the new mill at the Neuhof mine, belonging to the Graf Henckel von Donnersmarck Company near Tarnowitz, in Upper Silesia, on page 446.

Notwithstanding the perfection of modern concentrating machinery,

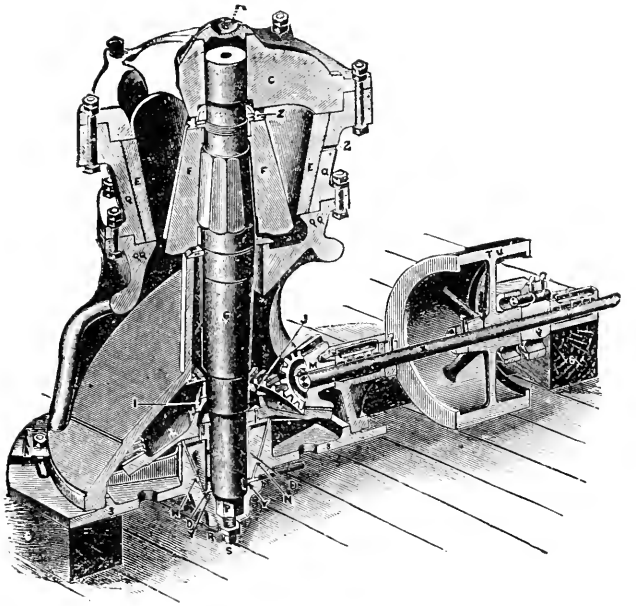


FIG. 147.—SECTIONAL VIEW OF GATES ROCK-BREAKER.

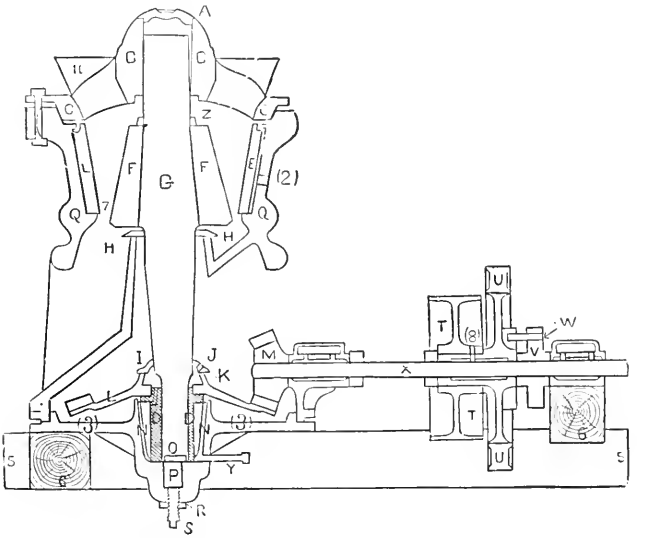


FIG. 148.—SECTION OF GATES ROCK-BREAKER.

there can be no two opinions as to the value of carefully hand-picking the rich lumps, as well as the sterile pieces of gangue, out of the ore

before it is crushed too fine, as not only is this the cheapest method, owing to the saving in metal effected through the absence of the losses which always occur after crushing, but also it enables the mill to treat a greater quantity of crude ore. This applies especially in the case of rich argentiferous galena, which, owing to its great friability, is apt to make a large proportion of slimes on crushing, and this always entails loss of mineral.

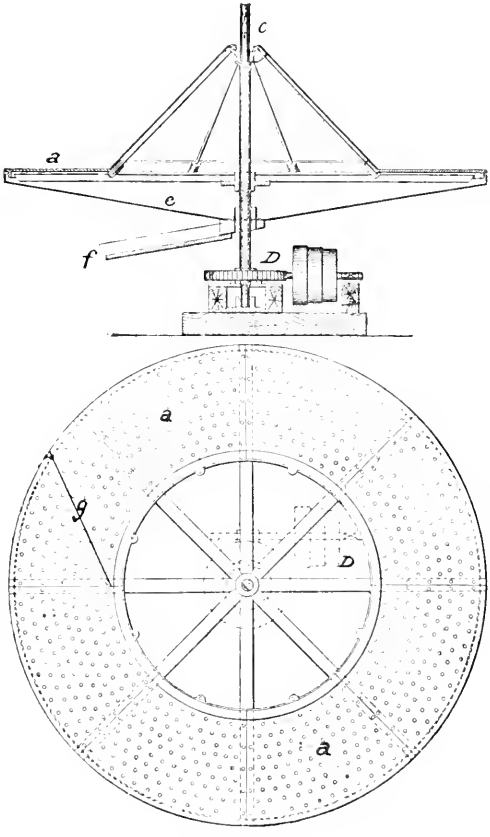


Fig. 149.—Rotating Picking Table.

The table on which this picking is carried out may either be a rotating circular one, as shown in fig. 149, around which stand the women who are usually employed at this work, or a long endless hemp belt running on rollers between two lines of women as in fig. 150.

From my own experience I am led to prefer this latter, as the number of women which can be employed at a rotating table is limited by its diameter, which again cannot be very great, owing to constructional difficulties; while in the latter the table can be made of any length, and, as there are two lines of pickers on each side, they have every opportunity of carefully examining the ore as it slowly passes in a constant stream under their eyes.

The rich ore can either be tipped into shoots, and thus conveyed into the magazine, or spalled by hand, in order to enrich it. In the case of highly argentiferous ore, the picking of even the smalls will well repay the cost, owing to the loss of silver which further crushing would involve.

While the women at the head of the table are sorting out the rich lumps, those at the foot are employed in picking out the sterile gangue,

so that, as far as possible, only ore which cannot be enriched without further crushing is allowed to fall over the end, and down an iron-lined shoot, into the hopper of the roller crushers below.

The quantity of ore sent on to the mill is thus materially reduced, though, of course there are some classes of mineral in which the ore is so finely disseminated through the gangue that the whole must be crushed down fine, and separated by jiggers, or even slime machinery.

The picking table also acts as a rough means of regulating the supply of ore to the roller crushers, and also admits of any iron or steel scraps, points of broken drills, nuts, and general odds and ends being taken out of the ore, which would otherwise pass on to the machinery and cause trouble. At one time I was much annoyed by the number of broken drill ends of hard steel which got into the roller crushers, damaging the face of the rolls, and making a horrible row in the mill. This I put a stop to by ordering the mine blacksmith, who sharpened the drills,

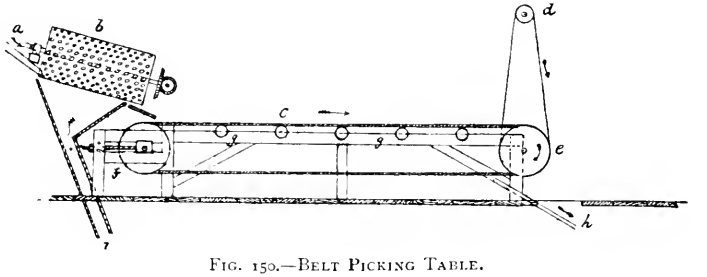


Fig. 150.—Belt Picking Table.

to refuse any broken drill without the broken piece, and to report any miner who brought one for repairs.

The miners were then fined for not picking up the broken bits, and finally the number found in the mill was reduced to almost *nil*. Another advantage of the belt table over the rotary is that the former while serving as a picking table acts also as a conveyor, and I have used it as such not only on the level, but with the belt rising at a slope of 1 in 10 where it was necessary to gain height in order to feed the ore into a smaller stone-breaker. I have also used both belt and rotary together, the former conveying the ore and discharging on to the latter which was placed at a corner when it was necessary to turn the stream of ore into the hoppers of a pair of roller crushers. The wear on the hemp belt is not heavy and with care they will last from 15 to 18 months.

The rotating iron picking table shown in fig. 149 is a circular table of thick sheet iron (A), sometimes perforated, fixed to a central shaft (C) driven by the gearing (D) which may be placed either at the top end of the shaft, or on the floor beneath the table, as shown in the illustration.

The ore is fed on to the table by means of a shoot from the crusher or

washing trommel; the water and fine ore drain away through the shield (E) and shoot (F), and the ore left on the table by the women or boys is carried round the table until meeting the fixed scraper (G), it is swept off it into a shoot, which delivers the mineral to the roller crushers.

The disadvantage of this kind of table is that, owing to its small diameter, the number of hands which can be employed in picking is limited. For small mills, however, it is a very convenient machine, and will not only help in saving rich ore, but will also relieve the mill from grinding a useless quantity of waste material.

If the diameter of a table of this kind is unduly increased then it has to be made exceedingly strong and heavy in order to stand the weight of the ore. A large table has also a tendency to sway and turn with a jerky movement which is not conducive to good picking.

Hand-picking has a double advantage, for not only is rich ore thus saved at the outset of the operations, but the waste rock picked out is also prevented from passing on into the mill, thus increasing the milling capacity, and to some extent reducing the amount of slimes made. The women or boys employed for hand-picking soon become expert at the task; but owing to the fact that they are guided by the colour of the ore and gangue it is difficult to get effective work done at night even by the electric light.

Ore Feeders.—It is important that the ore should be fed regularly to the stamps and roller crushers, or otherwise they will run to but little advantage. In the case of stamps there should always be a thin layer of ore upon the dies, so as to avoid loss of power by unnecessarily pounding the ore in the mortar box. Formerly the feeding of a stamp battery was done by hand, and, in fact, there are some mills in California and Nevada which still continue this. Automatic stamp feeders have, however, been introduced into by far the greater number of mills, and with these appliances it is the stroke of the stamp itself which regulates the speed, as when the dies are deeply covered with ore the stamp does not fall its full height, and consequently imparts but little motion to the tray of the feeder. On the other hand, when there is but little ore on the dies, the stamp falls through its full height and gives a full stroke to the lever of the feeding tray, which accordingly discharges a greater quantity of ore into the feeding box.

This action will be better understood by reference to fig. 151, which is a general view of Tulloch's ore feeder. A is a sheet iron hopper, or feed box, fixed in a suitable framing (O). At the bottom of this hopper is a tray (B) suspended on rods (C C). The ore fills the hopper, and would pile up and stick upon the tray or shoot (B) but for the travel and percussive movement which is given to it by means of the lever (E) and the recoil of the spring (M). The feeder is attached to the battery by

boring an inch hole through the guide block of the stamp stems, so that the end of the rod (J), will come under the tappet of the centre stamp, and a motion corresponding to that of the stamp is thus given to the rod (J). The motion is communicated by means of the lever (I P) and the adjustable rod (H), and so by the upright lever (E) to the tray (B), the sharp recoil of the spring (M) insuring a proper movement to the ore.

For very wet ores a variation of the Tulloch feeder, known as the "Challenge," is to be preferred. This machine is shown in fig. 152. The circular cast iron plate shown beneath the hopper, resting at an angle, is

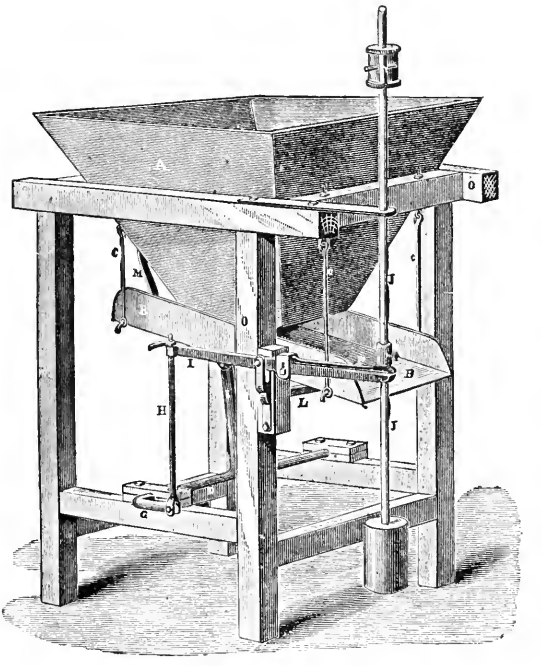


FIG. 151.—TULLOCH'S ORE FEEDER.

rotated by the bevel gear, which in turn is moved by an ingenious friction arrangement, varied by the blow received from the tappet on the rod, as in the Tulloch, corresponding to the requirements of the stamp. At each partial rotation of the feed table a small quantity of ore is scraped off by the stationary wings resting on the plate.

Too great importance cannot be attached to the regularity of the feed, whether to stamps or rollers.

With the slow running Cornish rolls used for coarse crushing it is not usual to employ a feeder, as the picking table above acts in that capacity, but with those used for recrushing and all fast-running rolls a feeder is

always attached. The principle is the same as that of the Tulloch, except that the motion is given to the feed tray by means of a cam fixed on a light shaft, driven from an end of one of the fixed roller shafts. This cam, together with the recoil of a spring, gives the necessary travel and shock to the tray, at the rate of two blows for each turn of the roller. The feed may also be assisted by means of a jet of water playing into the tray. The feeders are always supplied with the mill, and are absolutely necessary, as without them the moist ore is sure to jam in the hopper. Special feeders are attached to the improved types of Cornish rolls, with a view to spreading the stream of

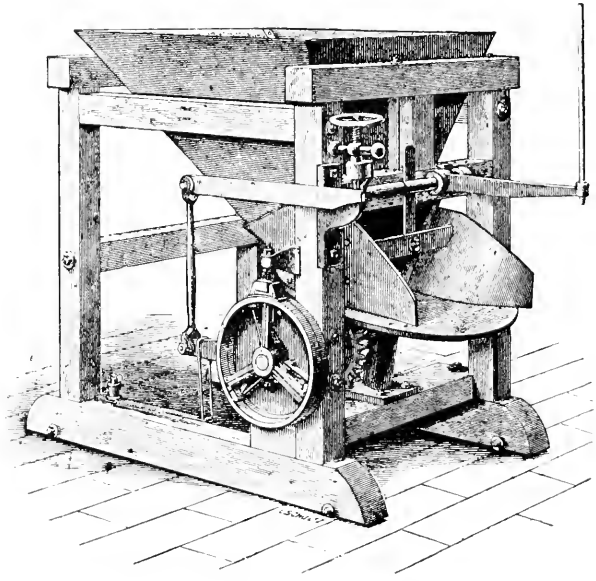


Fig. 152.—Challenge Ore Feeder.

ore as a thin sheet across the full width of the rolls, and thus insuring an even wear of their surface.

These special feeders are described with the machines to which they are attached.

In the illustration of the Cwmystwith Mill (Plate XX., page 458), it will be seen that there is a shaking screen between the outlet of the ore bin and the mouth of the stone-breaker. This serves the double purpose of a feeder to the stone-breaker, and of sifting out stuff under 1-in. which passes direct to the roller crushers below. This shaking screen is set on the incline, and the cam and shaft which drive it are heavy in proportion to the weight to be moved and the length of the stroke of the cam. They work successfully but are not entirely automatic, and a man

must be placed to watch the feed of each breaker, and remove any stones too large for the jaws. His labours, however, are much lightened by the action of the shaker, which greatly reduces the usual amount of shovelling and scraping, while at the same time it diverts the fine ore direct to the roller crushers.

The importance of a regular rate of feed right through a concentrating mill is very great, not only do all the machines run better, but they do better work and produce better concentrates of a more even grade and with less loss. Regularity of speed is a most important factor in modern milling, and is closely associated with regularity of feed. The first point, therefore, is to feed the stone-breakers with unvarying regularity, as with them the stream of ore starts. If they are fed intermittently, then the work right through will be intermittent, at one moment the trommels and elevators will be running light, and at the next they will be overloaded. This again affects the feed of the jiggers, which at times will have too much to do and at others not enough, and so what they actually do will be done badly. The remedy is to put a careful man at the stone-breaker and insist upon regular feeding on the principle of little but often, and the results of the milling operations will be much benefited thereby.

CHAPTER XI.

COARSE CONCENTRATION MACHINERY (continued).

Roller Crushers—Cornish Rolls—Cost of Crushing—Pulverising—The Krom Rolls—Gates Improved Crushing Rolls—The Huntington Mill—Marsden's Pulveriser—The Gruson Mill.

Roller Crushers.—The ore as crushed by the stone-breaker is usually of about the size of small macadam, containing an amount of fine smalls, according to its friability. After passing under the scrutiny of the pickers at the sorting table, the next process is to reduce it to a size suitable for jigging.

The almost universal practice in Cornwall and Wales, existing up to the present day, was to effect this crushing by means of a pair of crushing rolls, as shown in fig. 153. The fixed roll was coupled direct on to the axle of the waterwheel, while the other or movable roll was free to slide in the bearings as shown, being pressed up against the fixed roll by means of the long weighted lever. Below is seen a small screen or trommel. The coarse ore rejected by this falls into the "raff" or elevating wheel as shown, and is lifted up again and fed back into the rollers. The general dimensions of this type of crushing rolls are as follows: Pressing levers, vertical arms, $11\frac{1}{4}$ in.; horizontal arms, 144 in., loaded at end with weights, giving a pressure of 1100 lb. per inch of width for crushing the ore; average size of rolls, 24 in. × 15 in.; speed, from 4 to 8 revolutions per minute; capacity, $2\frac{3}{10}$ tons per hour to 3 mesh. The diameter of the waterwheel varies from 25 to 50 ft., and, as will be seen in fig. 308A (p. 460), it often drives the jiggers and buddles as well as the rolls.

I know of many of these wheels still at work, and the older style of mining "Captain" vigorously maintains that they are better than any other mill going.

The next improvement was in driving the rolls through gearing, as shown in fig. 154. These roller crushers practically consist of two hard steel cylinders, which are kept in contact by means of strong india-rubber buffers. The ore is fed between the rollers, and must either be crushed by them or force them open. They are driven by means of a belt and gearing. A fast and a loose pulley are provided. The fixed pulley has a heavy rim which acts as a flywheel, and helps to regularise the motion of

the rolls, and a handy arrangement is supplied for quickly shifting the belt in case of accident. In practice the toothed wheels between the rollers are found unnecessary, as the friction is sufficient to ensure the one following the other.

Next to the stone-crusher the rolls receive the roughest part of the work of the mill, and great care should be taken to have them made massive and extremely strong. They should be firmly bolted down, either

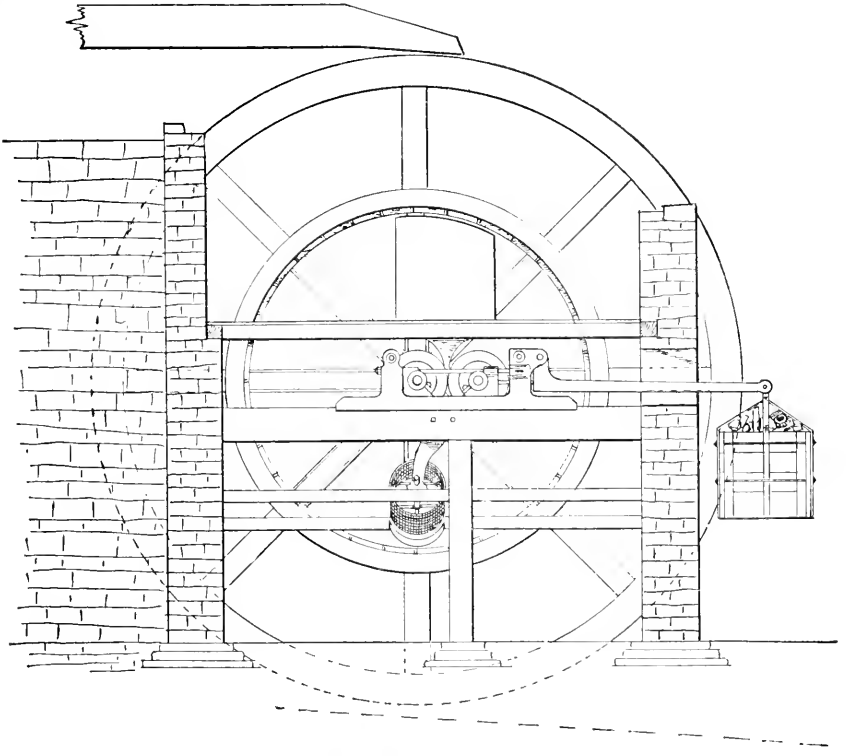


Fig. 153.—Waterwheel and Rolls.

to iron girders, strong timber baulks, or masonry, and all the nuts should be double, as owing to the great vibration they have a strong tendency to unscrew themselves, unless they are provided with check nuts.

The indiarubber springs now supplied instead of the cumbrous system of levers and weights, seldom require renewing; but the pressure should be slacked off each time the mill is stopped, so as to diminish the force required to set it in motion again, and to lessen the risk of the driving belt being thrown off in starting. The mouth of the feed hopper should also be closed before stopping, and the rollers allowed to run themselves empty.

If any large pieces of iron or steel pass on from the picking table to the rolls, in spite of the vigilance of the women, the driving belt will in all probability be thrown off, and much delay result. Small pieces, however, will pass through, and will either be found in the beds of the jiggers, or will be rejected by the sorting trommels, and be sent on with the coarse tailings to the rollers provided for recrushing, or back to the main rollers if there are no recrushing rolls, and here again they are a source of considerable trouble, which is avoided by careful picking.

The feeding of the large crusher rolls is to a great extent regulated by the picking table above, so that the mineral arrives in one continuous stream, and not in irregular masses. This is an important point, and affects the effective crushing power of the mill, as well as the regularity of its work and freedom from accidents. The other machinery also would

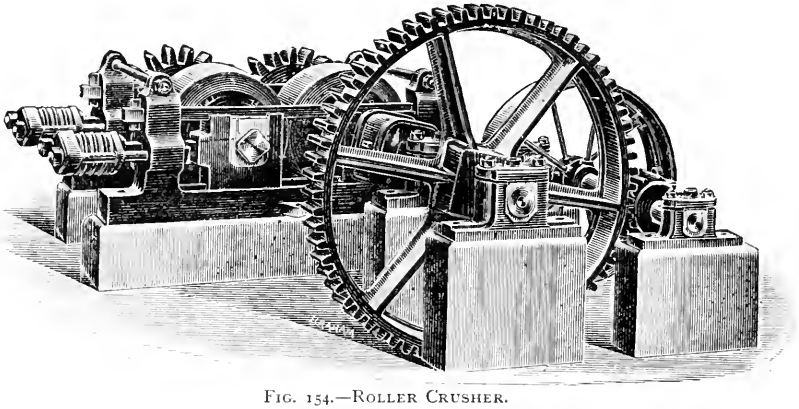


FIG. 154.—ROLLER CRUSHER.

suffer from any irregular feeding of the crusher; and as the jiggers give their best results when they are supplied with an even flow of mineral, it follows that the efficiency of their work depends to some extent upon the roller crusher. This remark applies more especially to the coarse jiggers which are fed direct from the trommels below the rollers, and not to those fed from the recrushing mill, the supply of ore to which is automatically regulated by a feeder, such as that shown in fig. 151.

The principal wearing parts of a roller crusher are, of course, the shells. These are made of chilled iron or steel, of varying diameters and width across the face, according to the capacity of the mill and the practice of the makers, varying from 18 in. to 24 in. diameter for the rough rolls, and 10 in. to 18 in. diameter for the fine crushing rolls, the width of the face being from 8 in. to 12 in.

A stout boss is cast on to the shafts of each the rollers, and this is turned down to a slightly coned shape to fit exactly into the hard shells, which are then secured by bolts and flanges. This is the foreign method;

while another practice is to cast the boss of an hexagon shape, about 2 in. smaller than the interior diameter of the shells. The space between the two is then filled up with oak wedges, into which iron wedges are afterwards driven.

A spare pair of shells, ready mounted upon their shafts, should always be kept in stock, so as to replace the ones in use whenever necessary. The operation of changing the rollers occupies a time which depends very much upon the situation of the crusher and the facilities for getting about the work. A set of blocks, chain and crab, as well as a screw or hydraulic jack, should be kept handy, and spare rollers as near as possible to the crusher. With everything thus prepared in advance, the operation should not take more than ten or twelve hours at the outside.

As soon as the old rollers are taken out the worn shells should be taken off, which is done by burning out the wooden wedges. A new pair of shells should at once be wedged on, and will then be ready, whenever wanted, whether in a few days or months.

The wedging on of the new shells is usually done by the carpenters. The axle is set up on wooden supports, and the shell fixed on at first loosely by wedges, and the whole turned round until perfectly centred; the wedges are then tightened up with a sledge hammer, and their ends sawn off, after which small iron wedges are driven in to complete the solidity of the work. The brass bearings of the crusher sometimes need replacing, and spare ones should be kept in stock. Usually only the half of the bearings which receives the thrust is of brass, the other half being of cast iron. Care should be taken to prevent the access of dust and grit to the bearings, and the iron protecting caps provided for this purpose should always be kept in their places.

Iron scrapers are used to remove any accumulation of dirt or clay from the rollers, and, as these are constantly wearing down, spare ones, made out of scrap iron or old boiler plates, should always be kept handy.

The rollers are sometimes jammed and stopped by an over supply of mineral, and require clearing, if possible, before the belt falls off. Sometimes this can be done by means of a bar, but this is a dangerous operation. If a bar is kept for this purpose it should be quite straight and smooth without a handle, so that if it gets caught between the rollers it may be snatched from the hands, which is not always possible when there is a handle to it.

The cost of crushing by means of rolls must depend largely upon the nature of the mineral to be reduced, the hardness of the shells, cost of material, and of labour, as well as upon the speed at which the rolls are driven. In Germany this latter varies from a circumferential speed of 90 ft. to 180 ft. per minute; while at a mill in France, with which the writer was connected, the rolls were 32 in. in diameter, revolving at a speed of 20 revolutions per minute, or say a circumferential speed of 160 ft. per

minute. If rolls are worked too fast power is lost, if too slow they are apt to stop if a hard piece gets between them, and in such a case a large proportion of coarse ore will fall through. My friend Mr. Philip Argall, of Denver, Colorado, United States America has made a thorough and scientific study of the question of crushing with rollers, and the results of his vast experience are to be found in a paper submitted by him to the London Institute of Mining and Metallurgy, and in his absence read by me on February 20th, 1902. Facing page 254 will be found diagrams extracted from that paper, showing the capacity in roller crushers of the modern type in cubic feet of mineral crushed per hour at given speeds and sizes.

The following particulars are given * in connection with a Cornish crusher operating upon steel grained lead ore associated with carbonate of iron, quartz, and hard shales: Diameter of rolls 21 in.; length of face, 19 in.; weight of new pair, 2700 lb.; weight of worn out shells, 1600 lb.; number of revolutions per minute, 8; speed on face of rolls, 42 ft.; size of stuff before entering, 20 to 60 mm.; afterwards, 0 to 6 mm.; weight crushed per hour, $2\frac{1}{2}$ tons; quantity of stuff crushed by a pair of rolls, 2000 tons; time required to take off and put on new rolls, 10 hours; number of hands required at crusher, 3; cost of pair new rolls, £18 3*s.*; cost of labour and material when changing, £1 7*s.* 6*d*; together, £19 10*s.* 6*d.*

Working under the above conditions, the total cost per ton of ore treated would be as follows:

Redemption of rolls (less allowance for old rolls) . . .	$1\frac{1}{2}d.$
Labour cost	$2\frac{1}{4}d.$
Steam-power, 5 horse-power	$5d.$
Wear and tear of machinery, oil, etc.	$1d.$
Cost of crushing 1 ton of stuff	$9\frac{3}{4}d.$

Owing to the feed not being regularly distributed across the whole face of the rolls, they have a tendency to wear in a groove in the centre, and when this takes place they will no longer crush fine. When both coarse and fine rolls are employed, as is always advisable, the same sized shells should be used for each, so that those of the fine rolls, when worn down, can be used for the coarse.

One or other of the shells is very apt to slip in its axle, and this causes the rolls to wear to a cone shape, and finally to jam themselves against the side frames. In order to obviate this it is the practice at some mills to make one shell about 4 in. wider than the other, when it is found that the smaller will wear regularly into the greater, leaving in time a flange on each side. This plan increases the friction enormously and is not to be recommended.

* "British Mining," by R. Hunt. London: Crosby Lockwood & Son.

In France the cost of a pair of shells with surfaces chilled to a depth of about 2 in. is approximately £16 per ton.

For the crushing of the tailings from the jiggers, either a smaller set of rolls must be provided or the reserve set of coarse rolls used for this purpose, if special arrangements for the conveyance of the ore to and from the rolls can be made. In some mills, where a set of rolls is devoted to fine crushing only, it is the custom to turn down their faces as soon as they become grooved. For this purpose a slide rest is rigged up across the framework, and the operation conducted as in a lathe; but as the metal of which the shells are constructed is excessively hard, it is a difficult and lengthy piece of work to turn them up true when once they are worn.

In other mills special pulverisers are employed, of which a description will be found on page 255.

To sum up, it may be said that the ordinary Cornish rolls are effective, simple, and cheap machines for crushing rock after the rock-breaker, either wet or dry. They are, however, employed where the crushing has not to be carried very far, as in the coarse concentration mills used for lead; though of late years, owing to their being made of an improved form, and driven at a higher rate of speed, they are not without advocates for their use for fine crushing in lieu of dry stamps. For this purpose the modern perfected type of fast-running roll is largely used, for dry crushing the Telluride ores of Cripple Creek.

When employed for fine crushing it is essentially necessary that the shells be of good material and kept true on the surface, as well as that the feeding should be regular and across the full width. These are qualities which are claimed by the makers of the Krom rolls, of which a description will be found on page 242. In some cases crushing has been successfully carried out by means of rolls, to pass a screen of from 20 to 30 mesh, but as yet there is not sufficient evidence to show that crushing with Cornish rolls can be advantageously effected to a finer grade than 30, especially when the ore is of a clayey character.

There is a general tendency in the present type of gold and silver mills to adopt a coarser crushing than formerly, and there is a considerable difference of opinion among mill men as to the need of fine crushing for the roasting of silver ores.

In leaching mills the limit of the coarseness of the crushing is determined by the results of the roasting, and as rolls produce a less proportion of fine dust than stamps, their use greatly facilitates the subsequent leaching process, and this is an obvious advantage. In amalgamation mills the employment of settlers limits the coarseness of the crushing.

Rolls make less dust or slimes than stamps, and are cheaper in first cost and erection; but, as the subsequent treatment of an ore

determines its method of crushing, no general comparison of stamps and rolls can be made. A comparison is only possible in the special cases where both methods of crushing are applicable.

Pulverising.—The coarse concentration required for the separation of the larger grains of various ores from the gangue which carries them, is followed by a fine concentration in order to affect the separation of the fine grains of mineral in the slimes; but this fine concentration

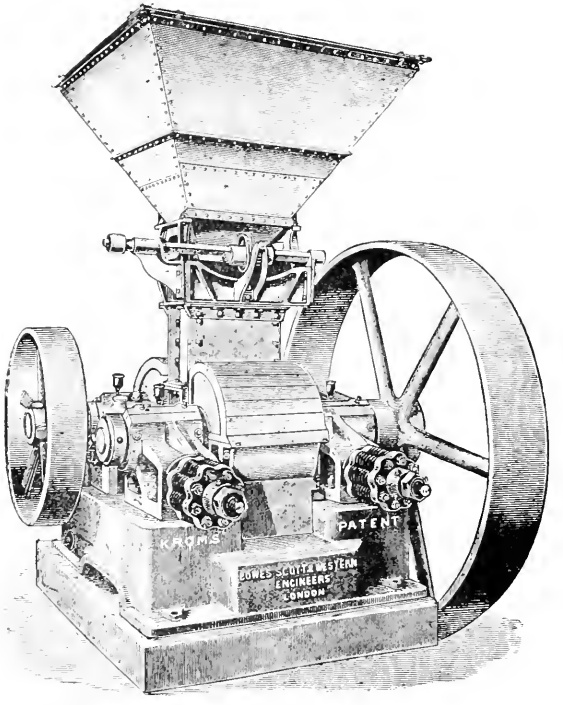


Fig. 155.—Patent Krom Roll, with Automatic Feed.

must have been preceded by a fine crushing or pulverisation of the mineral; for although a certain amount of dust or slimes is made during the coarse crushing, yet by far the bulk of the ore has to be recrushed, and, of course, when gold or silver ores are under treatment the whole of the ore must as a preliminary be reduced to a fine sand.

The number of machines which have been invented in order to effect this fine reduction is legion, but only a few of them have proved themselves of practical utility, and it is to those few, which will produce certain known results, that the present chapter is devoted, excluding however, the stamp battery which is described in Chapter XII.

The slow-running Cornish roll (fig. 154) is, when new, a fairly good pulveriser; but it is useless to expect that the machine, which after the stone-breaker, has to do all the rough work, will also do the fine pulverising; for, assuming that $\frac{1}{4}$-in. stuff is fed into a pair of rolls treating 2-in material, it follows that whenever the shells are opened out by a hard stone, a large quantity of fine stuff will pass through without being touched, and will continue to go round and round in an accumulating quantity. At first, when the shells are new, a certain amount of useful work may be done, but the small average effective result necessitated the treatment of the fine gravel under $\frac{1}{4}$-in. in separate pair of rolls. When once this was done, the question arose as to whether the machine could not be so improved

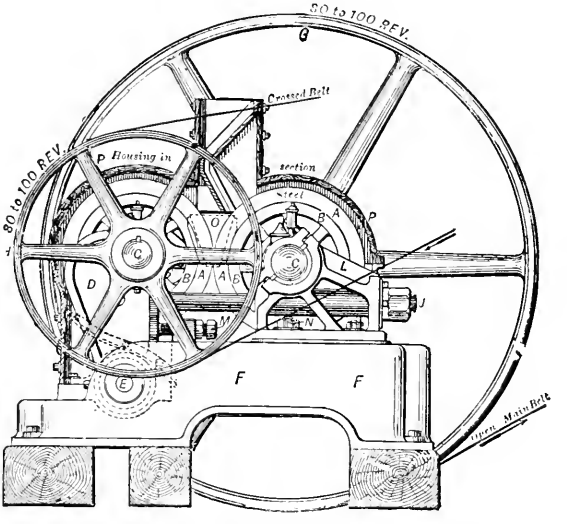


FIG. 156.—SECTION OF THE KROM ROLL.

as to compete with stamps when it was applied to reducing to sand mineral which was already crushed down to the size of gravel.

The result has been the perfection of the Cornish rolls up to what are known as the Krom rolls, and the Gates improved crushing roller, which, however, work best on the dry system—that is, when fed with ore not containing more than 5 per cent. moisture; and to the Huntington mill, which is used for wet crushing, and which is, perhaps, the most successful competitor as yet against stamps for certain classes of ore.

The Krom Rolls.—This machine, which is illustrated in fig. 155, and in section in fig. 156, consists of a pair of forged steel shells (A) $2\frac{1}{2}$ in. thick, rolled on to cast iron bosses (B) running upon the axles (C C).

The shells are 26 in. diameter, by 14 in. wide, and run at a speed of 100 revolutions per minute. The driving axle (C) is in fixed bearings, and carries the driving pulley (G) 7 ft. in diameter.

The second axle is set in a swinging pillow block fixed in two strong cranks (D D) of the end view (fig. 157) which rock upon the shaft (E) set in the cast iron frame (F). The shaft (M), to which the cranks (D D) are keyed, is 11 in. diameter, and set parallel to the roller shafts, so that the loose roller (B) must always move parallel to the fixed one. The one roller is thus firmly fixed in bearings rolled to the bed plate, the other can move parallel to it owing to its being fixed to the cranks of the rocking shaft. The rollers are pressed up close to each other by means of the springs shown in fig. 155, which can be adjusted so as to vary the pressure according to the nature of the ore. Upon the shaft of the loose roller a small pulley of 42 in. diameter is keyed, and this is driven at the same rate as the main pulley, its only function being to ensure the one roller following the other, which in the ordinary Cornish rolls is attained by means of the deep spurwheels.

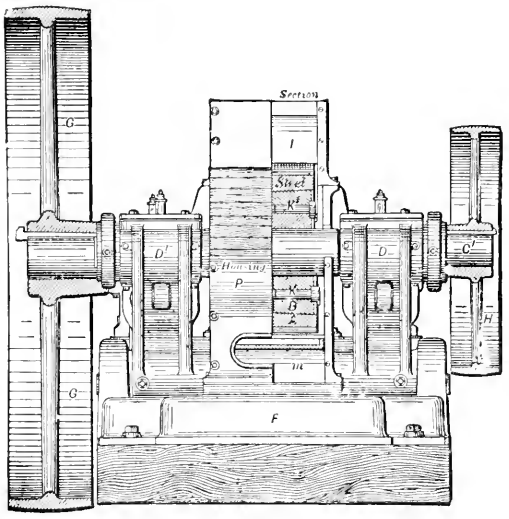


FIG. 157.—THE KROM ROLL (END VIEW).

The machine is very compact, a pair of 26-in. rolls occupies a ground space of 7 × 7½ ft. The tyres, which for a 26-in. roller weighing 816 lb. each, are held in place by two cast iron heads (B) which are slightly conical in shape. One of them is shrunk on the shaft, the other is slit on one side and slips on to it. Both the heads (B) are so placed on the shaft that the smaller diameter will be towards the centre. The steel tyre is turned out on the inside to correspond with this, so that it can be easily slipped over the permanent head and the loose core brought up to it. The two are securely fastened together by the bolts (K), so that when the movable head is drawn up to the permanent one, the slit in it closes up and makes it perfectly tight on the axle. The tyres can, it is said, be worn down to ½ in., and are worn until they are so thin as to become loose from expansion.

The rolls are covered with housing (P) to which an exhaust fan is

attached, for removing the fine light dust, which is carried to a dust chamber.

In order to ensure an even wear of the face of the rolls a special distributer is attached to the feed box which distributes the ore in a thin regular sheet across the whole width of the rolls, and to this even distribution must be attributed the long wear of the shells. At the Bertrand Mill, Cortey, Nevada, two sets of 26-in. rolls are stated to have crushed 15,000 tons of ore, at the rate of 150 tons in 24 hours, through a 16-in. screen without renewal. The capacity of the best stamps on the same ore would be about 2 tons per stamp per 24 hours, which makes the rolls equal to a 50-stamp mill, while the wear and tear, as well as the power required, are stated to be one-half that necessary for a stamp mill.

The Gates Improved Crushing Rolls.—I had an opportunity in 1900 of seeing several sets of these rolls at work at the mill of the Metallic Extraction Company, of Cyanide, near Florence, Colorado, U.S.A., where they are in use for pulverising the Cripple Creek ores dry previous to cyaniding. As roller crushers are now largely used both in South Africa and the States for dry crushing purposes, it will be well to preface the description of these high class rolls by a few words as to the general arrangement of a plant for dry crushing purposes, though the same remarks are applicable to the arrangements for wet crushing in a concentration mill.

With crushing rolls it is not possible to reduce rock or ore from the size in which it has been left by the breaker (probably $1\frac{1}{2}$-in. cubes) to a finished product (30 mesh, for example) at one operation. Therefore, in arranging plants, a gradual reduction should be provided for.

In dry crushing, a Gates 36-in. machine should reduce $1\frac{1}{2}$ in. ore to $\frac{1}{2}$ in. without difficulty from sand packing, and the 26-in. machine should reduce the $\frac{1}{2}$-in. stuff to No. 8 mesh without trouble. This 8 mesh product, passed through other 26-in. machines, should produce finished material with but a small amount of rejections returned from the final screens.

A 36-in. machine combined with a 26-in. machine,—the latter doing medium grade work,—and two other 26-in. machines for final finishing should do satisfactory work on ore of average hardness. With very easily crushed ores, less machines would suffice, and with very hard ores, more finishing rolls may be required, and the capacity in finished output will be in proportion to the fineness of the finished product. Such a combination of machinery is shown in the annexed diagram (fig. 158). Referring to the diagram, it will be seen that the arrangement is such that the product of the coarse rolls goes directly to a separating screen making two products ($\frac{1}{6}$- and $\frac{1}{2}$-in. mesh) and a possible oversize ;

the oversize is returned to the coarse rolls. The $\frac{1}{2}$-in. mesh product goes to the medium rolls and the $\frac{1}{8}$-in. mesh stuff to the final screens, the rejections of which feed the two sets of finishing rolls. The product of the medium rolls is returned to the first screen.

Thus the ore goes the rounds of the coarse or roughing rolls until it will all pass $\frac{1}{2}$-in. mesh. The $\frac{1}{2}$-in. stuff goes the rounds of the medium

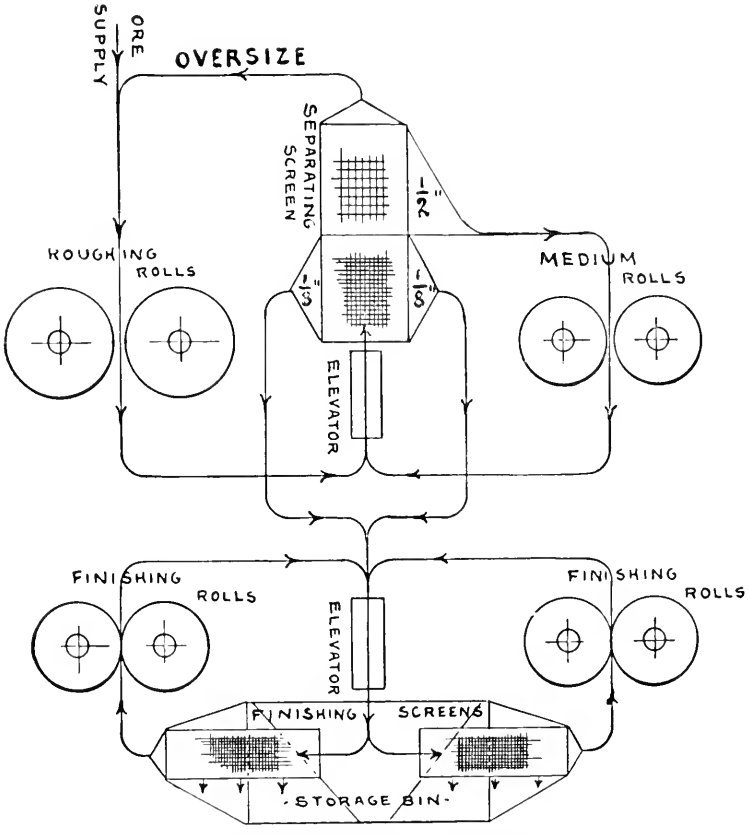


FIG. 158.—ARRANGEMENT OF DRY CRUSHING ROLLS.

rolls until it is all $\frac{1}{8}$-in. mesh and finer, and this 8-mesh product goes the rounds of the finishing screens and finishing rolls until it will all pass the final mesh. Observe, also, that any 8-mesh or finer product that has been produced by the roughing rolls does not get to the medium rolls, and that any finished sands that may be in the 8-mesh product is not burdened upon the finishing rolls, but goes to the finishing screens first. Thus immediately a particle is broken to a finished condition, it

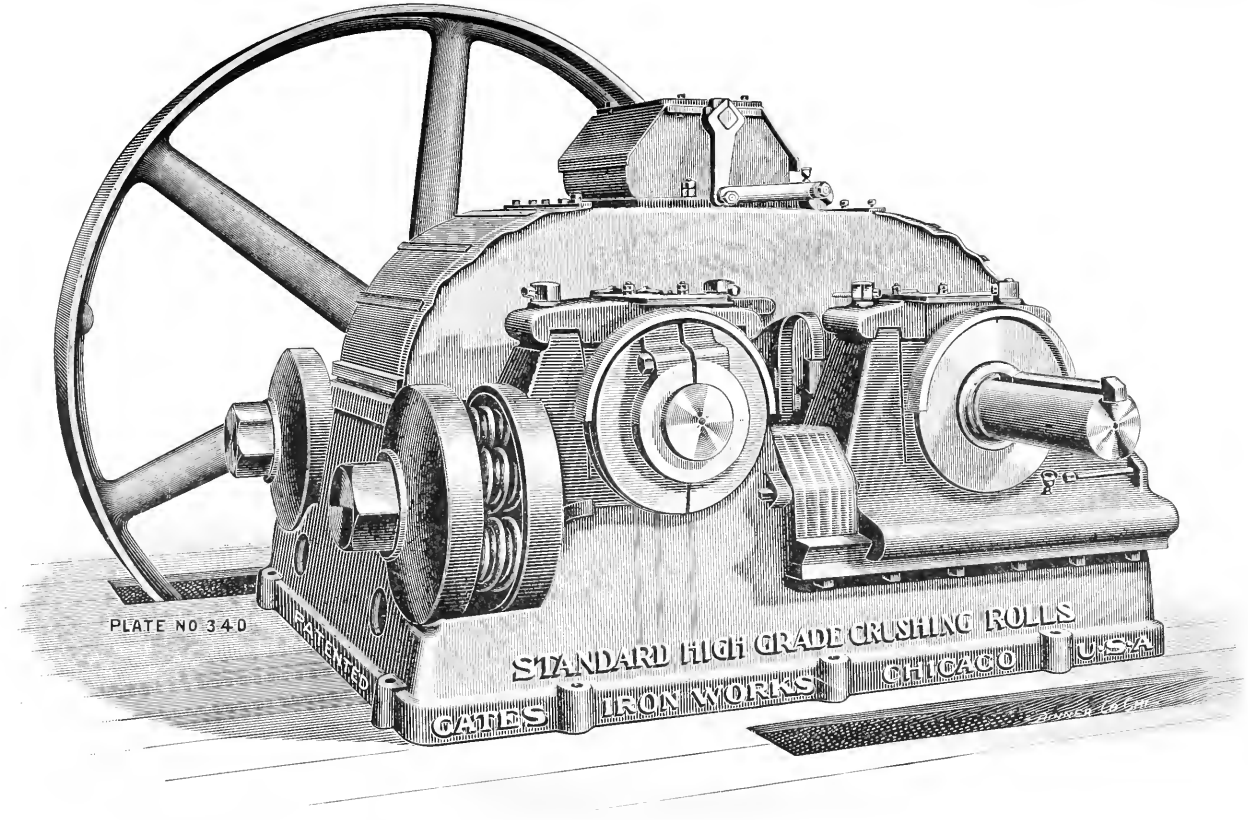


Fig. 159.—The Gates Crushing Roll.

passes directly to a finished product bin without again passing through the crushing machinery.

The mesh of screens used and the opening allowed between the rolls are modified to suit the particular case in hand, in order to properly distribute the load upon the different machines. The finishing rolls are always run with their edges in contact except when the shells are entirely new.

The capacity of the combination described when reducing to 30-mesh may approximate from 125 to 175 tons per 24 hours; 20-mesh, 200 to 250 tons per 24 hours; 16 mesh, 250 tons and upwards.

The speed at which it is desirable to run these rolls is 50 to 75 revolutions per minute for the 36-in. rolls and 75 to 125 revolutions for the 26-in. as at these speeds they give the best results.

The general appearance of a Gates high grade crushing roll is shown in fig 159. The main frame is cored and braced in a substantial manner with a view not only of meeting the requirements of stress and work put upon it, but also so as to avoid the usual dust collecting pockets of the outside rib form of construction. It forms a dust proof case for the machine reaching up to the centre line of the roll shaft, its hopper bottom converging to a point to which the spout leading to the elevation may be tightly secured. It is provided with seats for the dust housing, the sliding pedestals, and for the rigid roll journal box, and contains and preserves the alignment of all the working parts. It is broad of base and planed true of the bottom to simplify and facilitate the erection of the machine.

All these high grade rolls are made with specially designed journal boxes permitting the most perfect lubrication, which is a special feature of these machines. This company were the pioneers in the introduction of single-sided waste wiping journal boxes for this type of machinery, and they have worked a revolution in the cost of maintaining the efficiency of rolls by its use. This construction of roll journal boxes permits of wearing the same weight of babbit metal for a period of eight or ten times as long as in any other constructions, while the lubrication is perfect.

The journal boxes are made in one piece—a solid casting, containing a large wearing area, lined with the babbit metal. The conventional and superfluous cap is discarded and a large oil chamber is provided in its stead as in fig. 160. This chamber is filled with soft woollen waste saturated with oil, and so there is an area as large as the babbitted surface, constantly wiping oil upon the whole length of the journal. This soft lining catches and holds any grit or sand that may find its way into the box, and thus prevents heating and cutting of the shaft. Two openings, large enough to admit the hand, are provided and covered by leather or rubber dust-proof covers of original design,

which are attached directly to the pedestal cap, and are never dropped upon a dirty floor to become vehicles for the transfer of grit to the journal.

The roll shaft journal is always accessible in Gates rolls, and may be easily seen and examined by feeling with the hand along its whole length while in motion without the least danger. There is nothing to

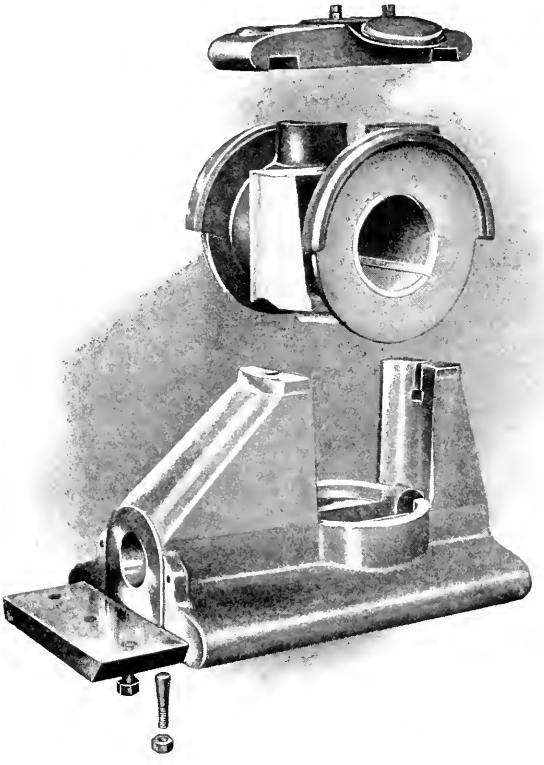


Fig. 160.—Journal Box of Gates Roll.

be taken apart to do this. Simply raise the flexible cover of the oil chamber and examine the parts. All the high grade roll boxes are made with swivel joints, and are interchangeable one with the other, permitting the fitting of a duplicate box into any of the four seats of the machine. The boxes are babbitted over a mandrel in the most convenient manner, entirely separate and independent of the machine. Thus extra boxes may be refitted at leisure and kept in stock ready for any emergency, making changes possible in the very shortest time. They are also made

with very large flanges at the ends, which provide liberal areas, against which the thrust collars, controlling the lateral movement of the roll shafts, wear.

All nuts larger than $\frac{3}{4}$ in. in size, used about the high grade machines, are split on one side and are fitted with bolts or cap screws to clamp them upon the threads. This is an expensive way of making nuts, but it is the only way of making them so that they will not work loose, and it obviates the nuisance arising from the ordinary construction of these parts.

A set of three special cast steel wrenches is furnished with each order to assist the operator in making rapid changes of wearing parts and quick adjustments; also a babbitting mandrel for the main journal boxes.

The pulleys used upon these rolls are specially made, ample in size, and extra heavy in construction. They have split and bolted hubs, adding to their strength and facilitating their removal when repairs to the journal boxes are necessary.

The high grade rolls are securely housed to prevent the dust (commonly prevalent in dry crushing) from passing out into the mill building.

The iron work of the housing is complete in one piece and is firmly secured to the main frame, being drawn into a tapered rocket and against a rubber belt lining by means of strong bolts; by reason of the taper joint it is not subjected to the common trouble of wearing loose. The housing has a large opening at either end, covered dust tight by a light canvas apron having a weight rod secured on its bottom end. This apron allows instant accessibility to the interior of the machine, and the faces of the rolls may be exposed to view across their whole width by simply raising the apron. This arrangement allows the most perfect accessibility for observation and repair of the roll surfaces—*a most important matter in wearing shells so as to prevent flanging.* The openings in the side of housing surrounding the roll shaft are planed and fitted with dust collars, held in place by springs in an efficient manner.

Shafts and Rollers.—The shafts (fig. 161) upon which the rolls are mounted are made of hammered iron, and being exceedingly large and heavy, provide against any deflection under the most serious strain to which they may be put. They are long enough to afford room for the journal boxes entirely outside of the housing, removed from the dust and sand. The shafts of the 36-in. rolls are 9 in. in diameter and 22 in. long in the journal box.

The shafts of the 26-in. machine are 7 in. in diameter and 18 in. long in the journal box. The shafts of the 26-in. and 36-in. machines are reinforced at their centres where the rolls are mounted, and are 8 in. and 12 in. in diameter respectively at this point. They are threaded and provided with large clamping collars, which are adjustable upon the threads to keep the rolls in proper lateral adjustment. Heavy brass wearing rings are interposed between these adjusting collars and

the ends of the journal boxes, and the whole is protected from dust by projecting shrouds cast upon the end of the journal boxes themselves. Lubrication is effected by means of a duct leading from an oil chamber cast on the inside of the journal box. The hubs which carry the roll shells are made of cast iron, and are in two pieces, one of which is pressed tight upon the shaft by a powerful hydraulic machine, the other being a loose fit and split on one side from the centre to the edge, allowing a clamping action in use. They are turned conical on their edges and are drawn into the double taper bored roll shell by means of four strong bolts, thus securing the shells centrally and rigidly upon the shaft.

Two heavy, long-threaded bolts are provided for forcing the sliding hub out of the shell when the latter is being changed.

Sliding Pedestal.—The movable roll is carried upon the usual

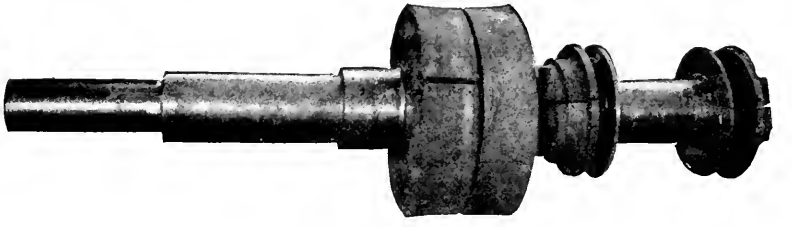


FIG. 161.—SHAFT OF GATES ROLLS.

sliding pedestal shown in fig. 160, the design and dimensions of which are peculiar to this machine. As ordinarily made, these parts are carried directly upon the main frame of the machine and in course of time wear the surface on which they rest so badly as to require expensive repairs, and frequently the loss of the entire main frame is entailed.

They are often made narrow of base, and are thus incapable of sustaining the constant pressure of collars controlling the lateral movement of the roll shaft without getting out of perpendicular.

In these high grade machines, the sliding pedestals are very broad of base, and do not wear upon the frame of the machine, but rest upon dove-tailed and renewable wearing plates, which are securely bolted to the main frame as seen in fig. 159. The bolts have a long taper and fit into carefully reamed holes which are drilled to templet, thus insuring at once a most rigid fastening and interchangeability. When this wearing plate is worn out it can be readily replaced by a new one, thus removing all liability of injury to the main frame. This is a feature found in Gates high grade rolls only.

Roll Shells.—The Gates Company have entirely abandoned the making of cast or chilled iron shells for high grade rolls. The laboratory tests have in combination with their long experience enabled them to select as their standard a material containing the right amount of carbon

to secure the best wearing results, and at the same time possessing sufficient malleability to enable them to be worn out without removing them from the machine. These shells, of which fig. 162 is an illustration, are rolled in a locomotive tyre mill turned true inside in a double cone, as seen in fig. 162, and at the edges, so that they fit on to the hubs with absolute accuracy, and when worn or grooved can be turned up true again on the face.

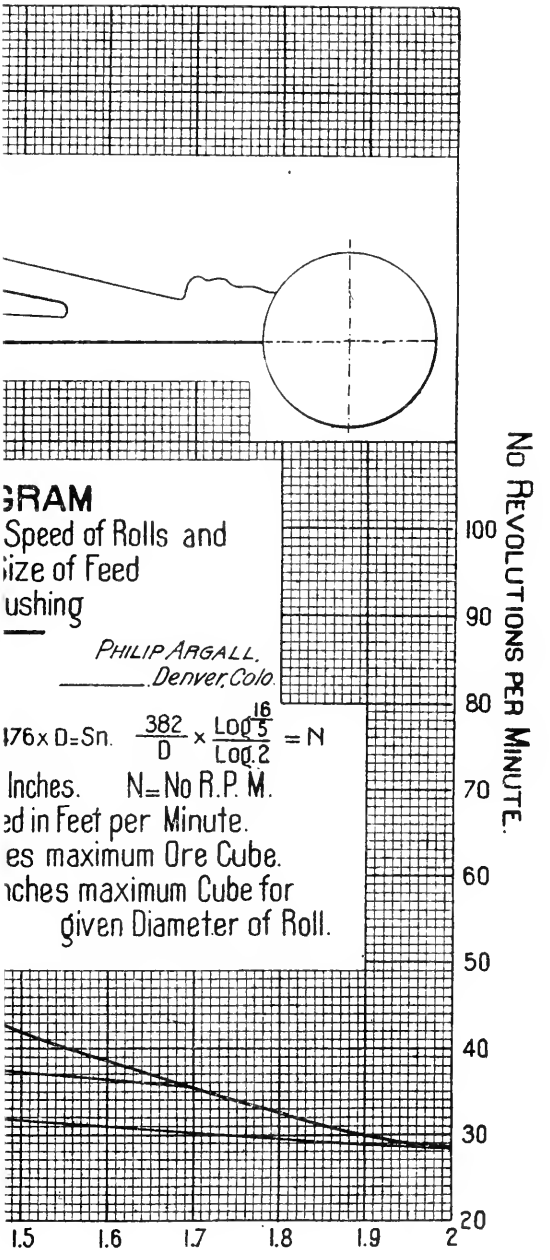
Fig. 162.—The Gates Roller Shell or Tyre.

Tension Bars.—The tension bars are made of hammered iron, and are of extraordinary section, capable of withstanding much more strain than can ever come upon them in the operation of the machine. They are turned and finished all over, threaded on one end and provided with large clamp nuts, by means of which tension of the springs is regulated to suit the work being done. They are finished the full length to fit the sliding and fixed pedestals, both of which are bored true, making them guides as well as tension bars.

The machine is provided with a special automatic feeder, as upon the regular feed and the even distribution of the ore across the face of the rolls so much of the efficiency of the machines depends. In fig. 163 will be seen one of these roller crushers being dismantled for the purpose of changing the shells.

This company also makes a lower priced but very reliable set of rolls called the "New Economic." In this roll the sliding bearings for the movable roll are done away with and an arrangement of rocking arms, journaled on to the frame, is substituted.

Speed and Capacity of Rolls.—In an excellent paper read before the Institution of Mining and Metallurgy, London, in February, 1902, my friend Mr. Philip Argall, of Denver, Colorado, goes most fully and scientifically into the construction and working of high-class rolls for dry crushing; for which purpose he, after a very long experience, considers them more efficient than any other machine. The same general rules apply to wet crushing, except that the crushing capacity is slightly greater. I am indebted to that paper for the subjoined particulars as to speed and capacity of rolls, and have the permission of the Council of the Institution to reproduce the three diagrams here given (figs. 163, 165, 166), illustrating the paper as published in the "Transactions."


GRAM
Speed of Rolls and
ize of Feed
ushing
PHILIP ARGALL.
Denver, Colo.
176 x D = Sn. $\frac{382}{D} \times \frac{\text{Log}\frac{16}{5}}{\text{Log}.2} = N$
Inches. N = No R.P.M.
ed in Feet per Minute.
es maximum Ore Cube.
nches maximum Cube for
given Diameter of Roll.
No Revolutions per Minute.
100
90
80
70
60
50
40
30
20
1.5
1.6
1.7
1.8
1.9
2

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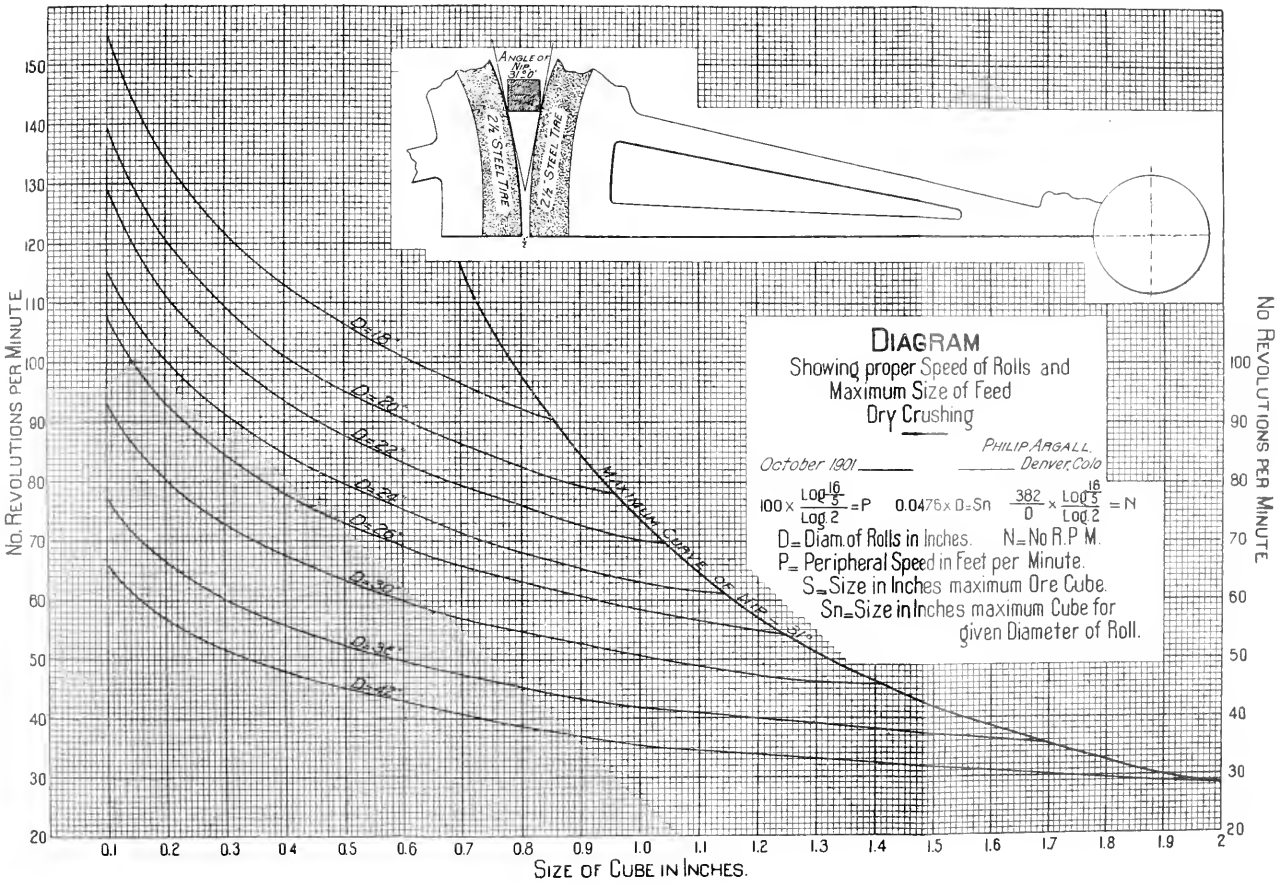


DIAGRAM
Showing proper Speed of Rolls and Maximum Size of Feed Dry Crushing
PHILIP ARGALL, Denver, Colo
October 1901
100 × Log 16/5 / Log 2 = P 0.0476 × D = Sn 382/D × Log 16/5 / Log 2 = N
D = Diam. of Rolls in Inches. N = No R.P.M.
P = Peripheral Speed in Feet per Minute.
S = Size in Inches maximum Ore Cube.
Sn = Size in Inches maximum Cube for given Diameter of Roll.
ANGLE OF NIP 31°20'
2¼ STEEL TIRE
2¼ STEEL TIRE
D=6"
D=10"
D=22"
D=24"
D=26"
D=30"
D=36"
D=42"
MAXIMUM CUBES OF ORE
NO. REVOLUTIONS PER MINUTE
NO REVOLUTIONS PER MINUTE
SIZE OF CUBE IN INCHES.

Fig. 163.

(To face p. 252

The circumferential speed of rolls varies largely in practice—from 30 to 40 ft. per minute on the old Cornish roll to from 800 to 1000 ft. per minute of the modern high-speed rolls. Mr. Argall says that he is convinced from his own long experience, that there is a speed of roll for each size of material, which will give the best result, or, in other words, where the maximum capacity is gained with the minimum of power.

These speeds were correlated by him, and from them the formula and diagram shown in Plate V. (fig. 163) were deduced. In reducing coarse ore with rolls a ratio of four to one should never be exceeded, crushing, say,

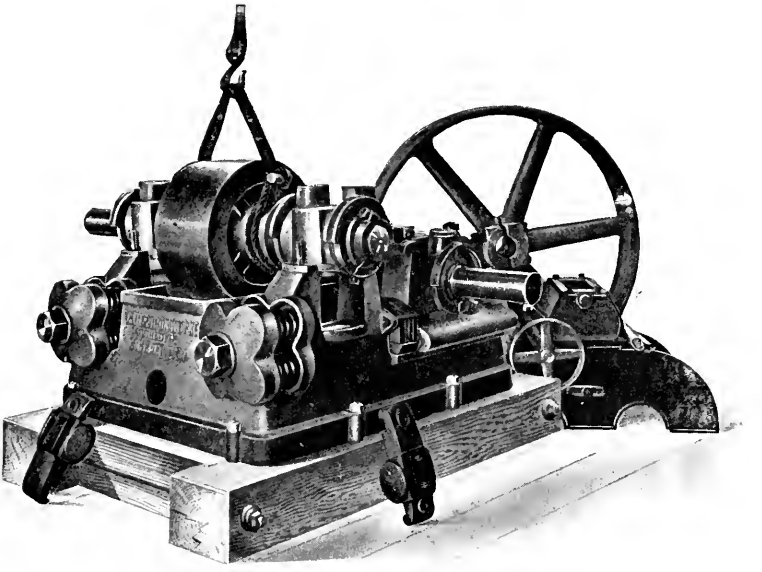


FIG. 164.—GATES ROLLER CRUSHER DISMANTLED.

from 2-in. cubes to $\frac{1}{2}$-in., from $\frac{1}{2}$-in. to $\frac{1}{8}$-in., and so on. In the diagram, it is assumed that the roll is set with $\frac{1}{2}$-in. opening between the tires or shells, and is crushing from 2-in. to $\frac{1}{2}$-in., and so on, proportionally for other rolls. In each case the space between the rolls is equal to the mesh to which the roll is crushing. There is, or rather should be, a relative proportion between the diameter of the rolls and the size of the particles fed into them, more especially in crushing the larger cubes, and it is manifest that if the size of the ore cubes materially exceed the "angle of the nip" they would merely dance around and will not be drawn down and crushed.

In the diagram, also, the speed curves of the various rolls are terminated on the right by another curve, which may be called the curve

of nip. Taking, for example, the speed curve of a 42 in. diameter roll, it is terminated by the curve of nip on the 2-in. cube line at the 28 ordinate, showing that to crush 2-in. cubes a 42-in. roll is required, and that the proper speed is 28 revolutions per minute. Taking a 26-in. diameter roll, the maximum sized feed is 1·25 in., and the speed for these cubes is 55 revolutions per minute. While for $\frac{1}{2}$-in. cubes the speed is 73 revolutions for 0·25-in. cubes, 88, and for $\frac{1}{20}$-in. 108 revolutions per minute.

The theoretical capacity of rolls is described by Mr. Argall as the number of cubic feet per hour which would be rolled out in a ribbon, the length being the peripheral travel of the roll in one hour; the width, that of the roller forces; and the thickness, that of the distance between the rolls. This may be expressed mathematically as:

$$\frac{P \times W \times S \times 60}{1728} = C.$$

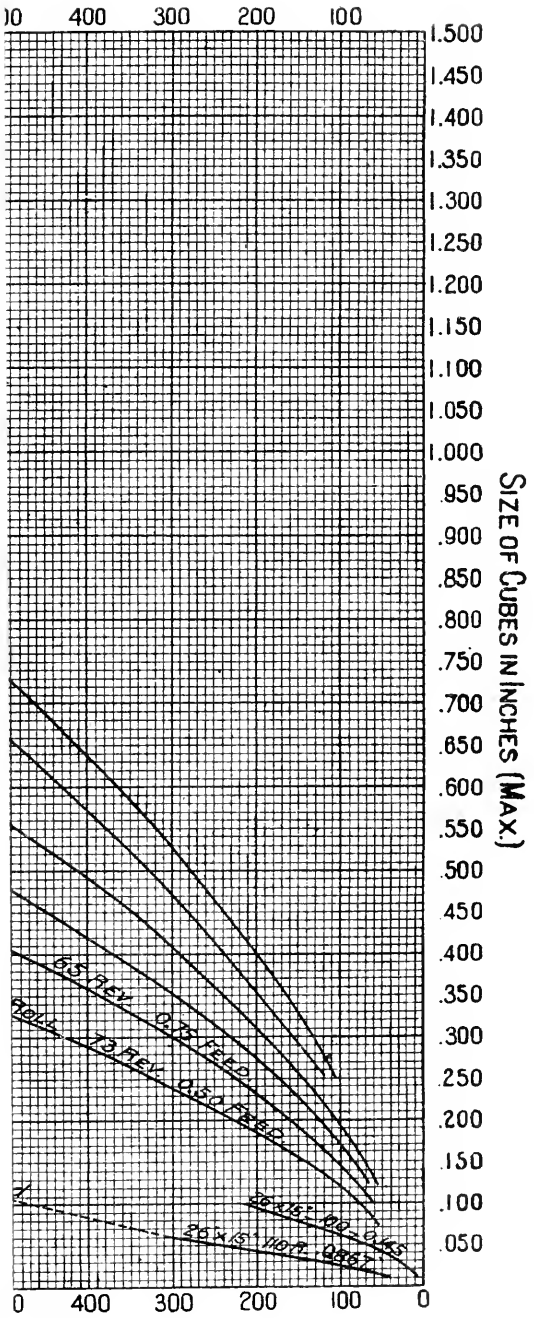
Where P = The peripheral speed in inches per minute.
W = Width of roll forces in inches.
S = Space between rolls in inches.
C = Capacity in cubic feet per hour.

Such a ribbon would, of course, not be homogeneous; it would have spaces and cavities unfilled, and consist of particles of every size from the largest that could pass through the spaces between the rolls down to the finest dust.

Taking, for example, the case of a 26-in. × 15-in. roll, 60 revolutions per minute crushing from 1-in. to $\frac{1}{4}$-in. The theoretical capacity is according to the formula at once found to be 589 cube ft. per hour, taking the mean diametre of the roll at 24-in. The actual capacity of *finished* product in cube feet per hour is most difficult to obtain, but can be closely approximated.

Following up the case just mentioned, the maximum size cubes are 1 in., the minimum just a little coarser than $\frac{1}{4}$-in. as fed to the roll. Now as the different varieties of ore do not break alike, one sort may have as much as 15 per cent. more say of $\frac{1}{2}$-in. cubes in the feed than another, and would consequently give a larger percentage of finished product after passing through the rolls. Mr. Argall's experiments show that there is a very close relation between the percentage of reduction and the amount of finished products for any given ore. By percentage of reduction he means that an inch cube reduced to $\frac{3}{4}$-in. is 25 per cent. reduction, to $\frac{1}{2}$-in. 50 per cent, and to $\frac{1}{4}$-in. 75 per cent.

Referring to the third of the three diagrams reproduced here (Plate VII., fig. 166), on the left an inch is divided by horizontal lines into one hundred parts, the scale extending 2 in. in height; next there is a series of diagonal lines to give the percentage of reduction at the given sizes; and lastly, a diagonal line marked "Percentage of finished product for given


400
300
200
100
0
1.500
1.450
1.400
1.350
1.300
1.250
1.200
1.150
1.100
1.050
1.000
.950
.900
.850
.800
.750
.700
.650
.600
.550
.500
.450
.400
.350
.300
.250
.200
.150
.100
.050
SIZE OF CUBES IN INCHES (MAX.)

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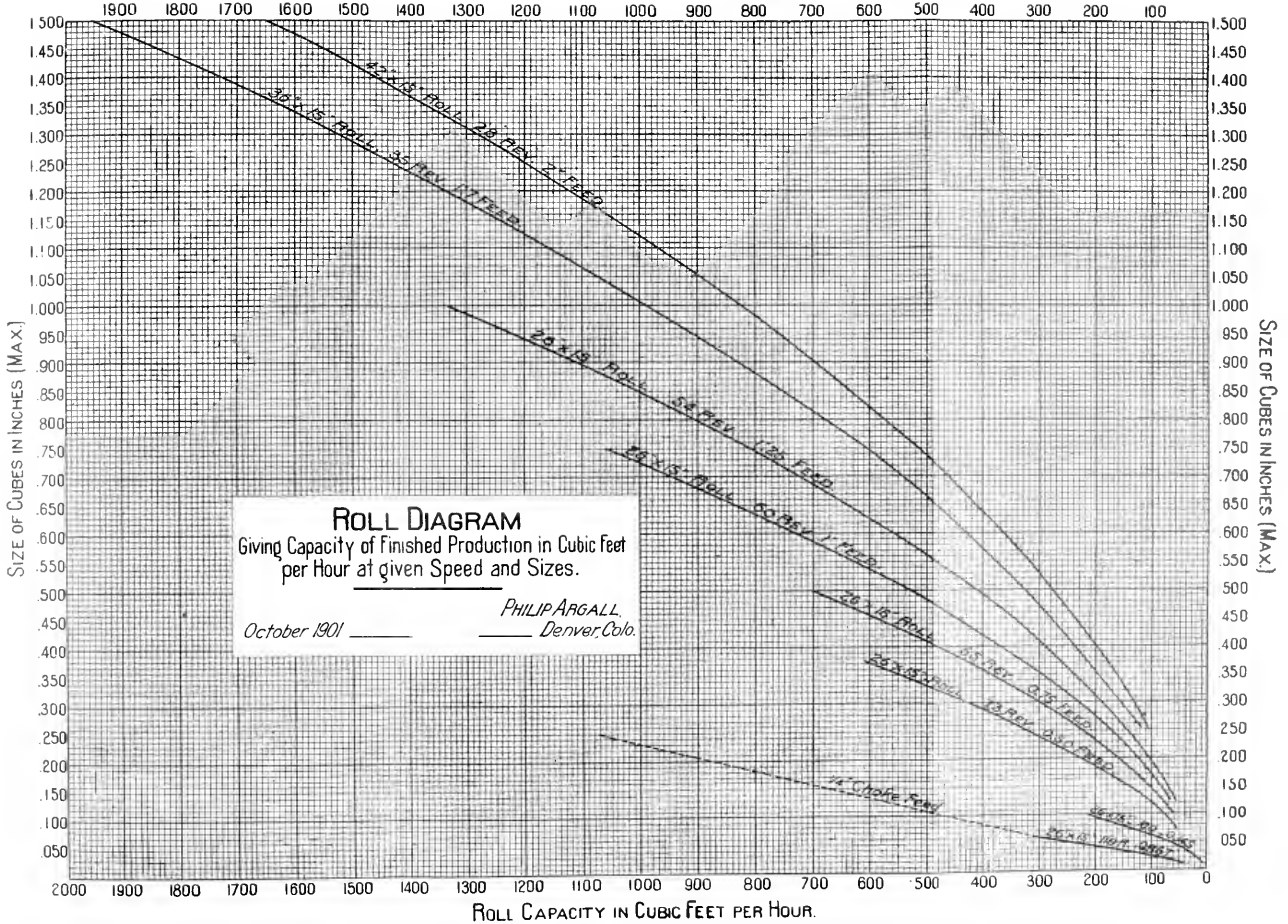

ROLL DIAGRAM
Giving Capacity of Finished Production in Cubic Feet per Hour at given Speed and Sizes.
PHILIP ARGALL,
Denver, Colo.
October 1901
SIZE OF CUBES IN INCHES (MAX.)
SIZE OF CUBES IN INCHES (MAX.)
ROLL CAPACITY IN CUBIC FEET PER HOUR.

Fig. 165.

[To face p. 254

percentage of reduction." This curve of *finished product* he has fixed from actual experiments with quartzose ores of medium crushing qualities and may be considered correct for average conditions with first-class rolls.

Applying this diagram to the specific case already mentioned—that is, of 1 in. to $\frac{1}{4}$ in.—and following the diagonal line from 1 in. on the left, it will be found to intersect the $\frac{1}{4}$-in. horizontal line at the ordinate marked 75 per cent. reduction, showing that the maximum reduction in the crushing powers was 75 per cent. Taking 75 per cent. on the right hand of the diagram and following the horizontal line, it will intersect the curve of finished product at the 30 per cent. ordinate, showing that for 75 per cent. reduction the finished product per hour is 30 per cent. of the theoretical. This latter has already been found by calculation to be 589 cube ft. per hour, 30 per cent. of which gives 176 cube ft. per hour of finished product, and so on, for any ratio of reduction shown on the diagram.

The capacity in cube feet per hour of various sized rolls, running at the speeds most suitable for the size of feed is shown in the second of the three diagrams here reproduced (Plate VI., fig. 165), which is compiled from the first (Plate V.) and third (Plate VII.). The tonnage capacity of the rolls is obtained by calculating from the weight of one cube foot of ore which obviously varies according to the nature of the ore under treatment and its specific gravity.

To those who are desirous of studying the construction and capacity of high-class rolls, their efficiency and working costs, I would strongly recommend a careful perusal of Mr. Argall's paper, a small part only whereof is represented by the summary just given.

The Huntington Mill.—The improved forms of roller crushers already mentioned are especially adapted to dry crushing, and do not present any striking departure from the old-fashioned Cornish rolls, except that they are first-class pieces of machinery, made with mechanical accuracy which was not formerly the case.

In the Huntington mill, however, an entirely new principle is brought into play. The rolls, instead of being fixed on parallel shafts pressed together by buffers, are suspended vertically, and crush by the centrifugal force which is called into play when the frame on which they are hung is set in motion.

The mill has now been in practical use for many years as a competitor with stamps, and the following are the advantages which are claimed for it:

The cost of same capacity is not more than one-half that of stamps.

Freight to mine, one-fourth that of stamps.

Cost of erection at mine, one-tenth that of stamps.

It runs with one-third the power per ton of ore crushed.

The wear is less than that of stamps.

The wearing parts are easily duplicated.

It has a much better discharge, and leaves the pulp in better condition for concentrating.

It is a better amalgamator, saving fully nine-tenths of the gold in the mill (the balance can be saved on plates in the usual manner).

Its simplicity of construction obviates the need of mechanical skill.

It is continually crushing without waste of power, as with stamps.

The accompanying drawing (fig. 167) shows clearly the construction of the mill; and in the case of a 5-ft. mill having an output equal to 10 head of stamps, the weight complete is 4 tons 18 cwt., the power

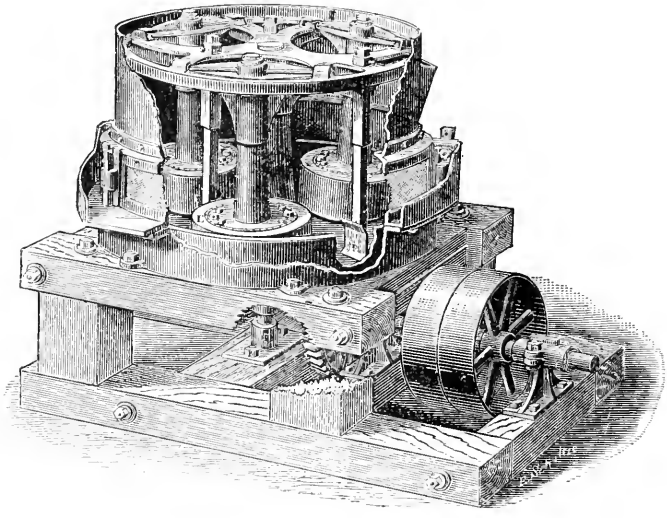


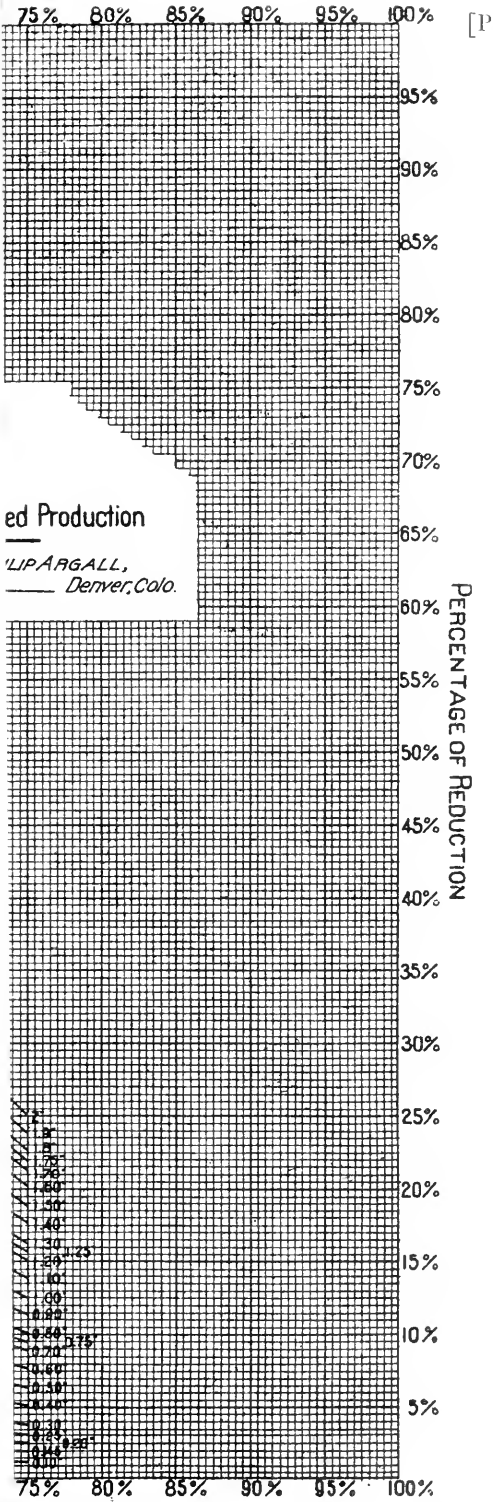
Fig. 167.—The Huntington Mill.

necessary to drive the mill being 6 horse-power. The inside diameter of the pan of the mill is 5 ft. The vertical driving shaft carries a frame from which four rollers are suspended, each with heads 16 in. diameter. These rollers are covered with removable shells, as in the case of the Cornish rolls; and being hung from trunnions carried on the framework, they fly outwards whenever the mill is put in motion, and crush the mineral between themselves and the steel ring, which forms the framework of the mill, with a force varying with the speed which is about 70 revolutions per minute.

The discharge of the ore is through the screen fixed for half the circumference of the mill just above the roller path or crushing ring.

An adjustable scraper is fixed in front of each roller, which dashes the mineral and water on to the crushing ring.

The rollers are so slung that a space of 1 in. always remains between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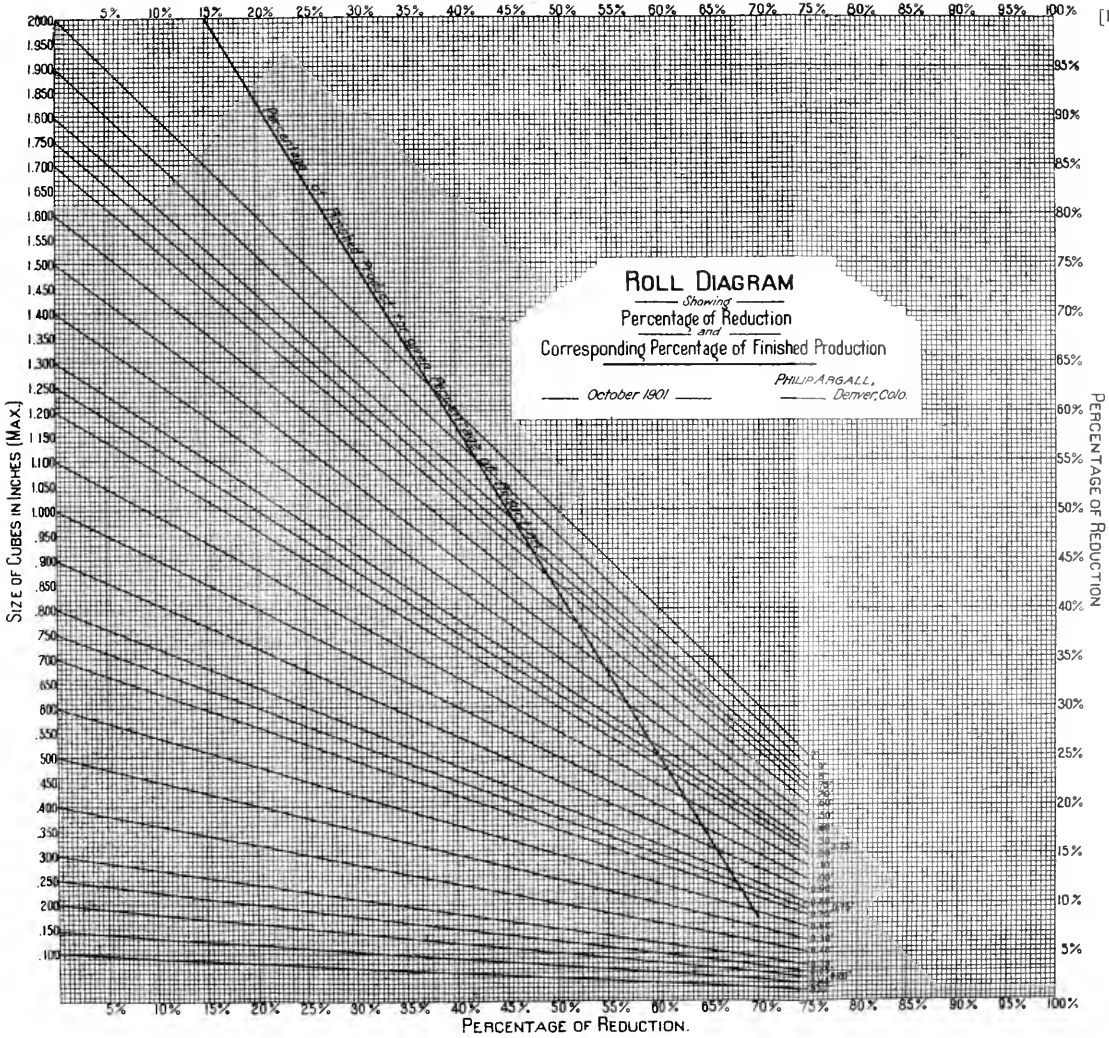


Fig. 166.

[To face p. 250

them and the bottom of the crushing pan, and into this mercury is put, and inside amalgamation takes place when crushing gold ores. For the effective working of the mill, the same considerations should be observed as for all other types of crushing machines; the mill should not be expected to do the work of a stone-breaker. The ore supplied to it should first of all be reduced to under $\frac{1}{2}$ in., and the feed should be regular. One difference between this mill and the stamps is, that the centrifugal motion throws outward against the crushing ring all the heavier portions of the ore, in contradistinction to the lighter and smaller particles of ore which always intervene themselves between the crushing surfaces in a stamp battery. The mercury is not beaten or pounded by the machinery, and thus flouring is minimised. The sulphides are not reduced to an impalpable powder difficult to concentrate to the same extent as in most machines, and consequently are in a better state for concentration.

The capacity of a Huntington mill is estimated as follows, when working upon ordinary gold quartz:

Diameter of Pan.	Weight.	No. of Revolutions.	Capacity per 24 hours.	H.-P. required.
$3\frac{1}{2}$ ft.	7,000 lb.	90	12 tons	4
5 ,,	11,000 ,,	70	20 ,,	6
6 ,,	20,000 ,,	55	30 ,,	8

The pulp passing through the screens is treated upon amalgamated copper plates placed in front of the mill as in a stamp battery, and can afterwards be concentrated upon fine vanners or by other means.

My own experience with Huntington mills has been very satisfactory. The material crushed was hard quartz, jigger tailings all under $\frac{1}{2}$-in. mesh crushing down to 1 millimetre $= \frac{1}{25}$ in. The quantity crushed was one ton per hour, the stuff being fed into the mill regularly and automatically by means of a Challenge feeder. At first there was a tendency to heating of the bottom bearing, owing to the entrance of grit and dirt, but when this was kept away the difficulty disappeared. I have not used them for crushing gold quartz, but have seen them used for this purpose in California, with excellent results as reported to me by the mill men. There are many of them in use also in South Africa.

Marsden's Pulveriser.—The success of the Blake machine as a stone-breaker naturally led the inventor to endeavour to adopt the same principle to the fine crushing of ores, the result being the production of the machine shown in fig. 168, which is so arranged as to allow nothing to pass away from it until it has been reduced to the degree of

fineness controlled by the size of the mesh in the trommel fixed above the crusher. P is one of a pair of heavy flywheels; G is the driving pulley; F is a connecting rod, acted upon by the crank shaft (P′) and working the lever (C) whose fulcrum is at D, giving a downward and forward motion to the grinding jaw (B).

At the commencement of every revolution till the centre is reached, the

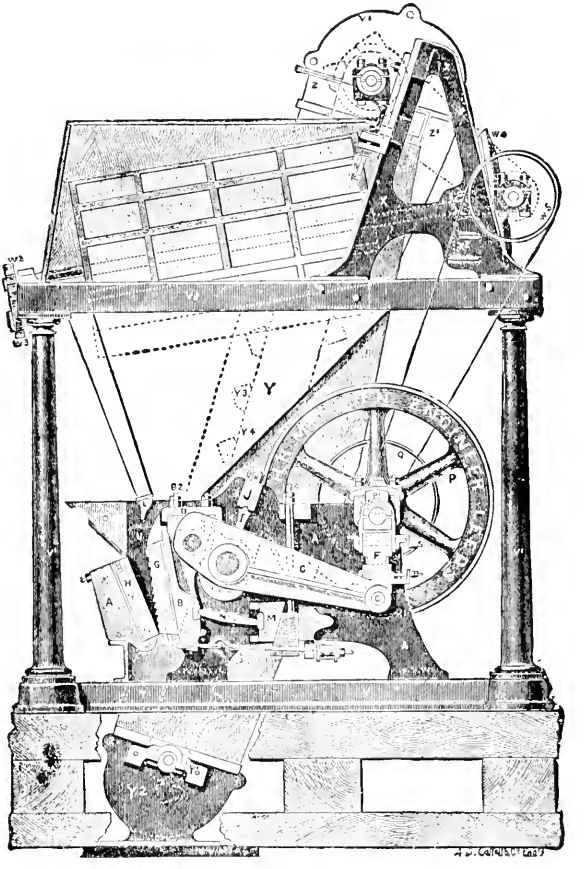


FIG. 168.—MARSDEN'S FINE ORE PULVERISER.

connecting rod draws up the end of the lever, which causes the grinding jaw to have a forward and downward motion of immense power upon the material in the mouth between jaw faces (H and G). At the remaining portion of the revolution the exact reverse takes place, and the material operated upon falls into an elevator at the side, which conveys it to a polygonal screen fixed over the machine, covered with gauze according to

the fineness of product required. All that is not fine enough passes out at the end of the screen through a small shoot (L) into the mouth of the machine, and is again operated upon with the regular feed.

The machine is adjusted, as in the stone-breakers, by means of the wedge (M), and the fineness of its product is regulated by the mesh of the screen. It can be used either for wet or for dry crushing with equal advantage, and from personal experience of it is well adapted for the work of pulverising.

The quantity which they will pulverise per hour necessarily varies with the material under treatment, as does also the power required to drive the mill. The wearing parts are the two jaw plates and the two side plates. These machines are made in five different sizes, and one with jaws of 12 in. × 3 in. at the mouth will crush 10 cwt. per hour down to 2500 holes per square inch, for which purpose it would require 5 nominal horse-power. Each machine would do approximately 20 per cent. more through 1600 holes, 30 per cent. more through 900 holes, and 40 per cent. more through 400; while for crushing finer than 2500, it will do 25 per cent. less through 4900.

I have used this machine for the purpose of pulverising hard limestone in Wales, with very satisfactory results.

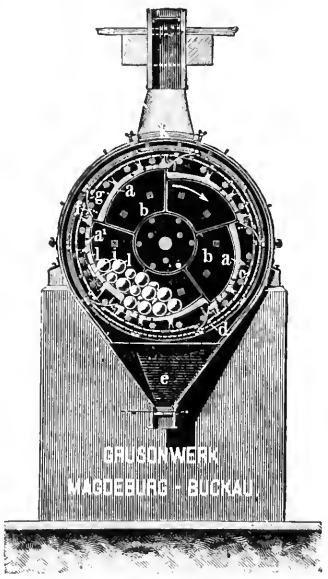


FIG. 169.—SECTION OF THE GRUSON BALL MILL.

Gruson Patent Ball Mill.—Numerous attempts have been made to construct pulverising mills upon the ball principle, and the failures have been almost as numerous.

The Gruson mill, manufactured by the Gruson Company, of Magdeburg-Buckau, is shown in figs. 169 and 170. It consists of a steel drum slowly revolving on a steel shaft. Inside are a certain number of hard steel balls of different diameters, which, on the revolution of the drum, continually fall upon and grind the ore, which is fed into the mill from the hopper (H).

It will be seen that the hard steel lining plates (*a a*) are so arranged that the balls fall from one to the other, each being perforated with a number of holes through which the crushed ore falls first on to a perforated plate (*c*) which acts as a protector to the fine circumferential sieve (*d*). The ore which is insufficiently crushed is returned into the mill by the guide plates (*g*), and no ore can leave the mill unless crushed down

to the mesh of the outer sieve (*d*). The sides are covered with hard steel plates (*b b*), and the ore is fed in from the hopper by means of a screw propeller fixed on to the shaft.

The mill will work either dry or wet, and the pulp falls into the hopper (*e*) which forms part of the exterior fixed casing of the mill. In dry crushing, if it is desired to remove the fine dust, the upper funnel (*k*) is connected

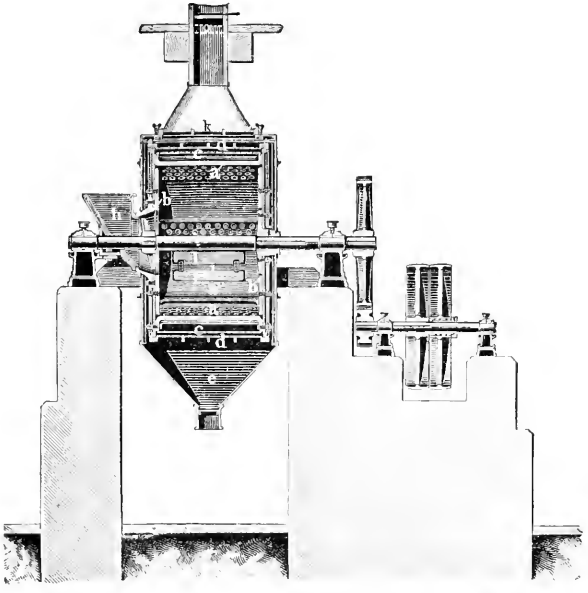


Fig. 170.—Cross Section of the Gruson Ball Mill.

with an exhaust fan which carries away the light impalpable powder to be deposited on a dust chamber.

All the working parts are made of the best drilled iron and cast steel; and the makers claim that, owing to their long experience in steel making for armour plates and war material, they have succeeded in turning out a metal which will resist the wear and tear inseparable from a pulverising machine. I have no personal acquaintance with this machine, but I have heard good accounts of the work it has done in the dry and wet crushing of gold ores.

CHAPTER XII.

COARSE CONCENTRATION MACHINERY (*continued*).

Stamps—Specification of 10-Stamp Battery—The Iron-framed Battery—Steam Stamps —The Tremain Steam Stamp—Imperfections of Stamp Batteries

Stamps.—Machines for the purpose of pulverising ore by means of stamps imitating the action of a spalling hammer were in use some three centuries ago in Cornwall, and, indeed, in some of the smaller mines of that county very old-fashioned machines, showing but little improvement in the original make, are still in use. Of these, however, it is not our purpose to speak, and we will at once proceed to the modern stamp batteries, as shown in fig. 171, a specification of which will be found on page 268.

It must not, however, be assumed that the stamp battery is the most perfect machine of its kind. It is, perhaps, the most perfect, in an all-round way, which has yet been invented.

Amongst its defects are a bad classification of the ore or pulp which consists of all sizes of grain, from an impalpable powder up to the size of the mesh of the screen employed, and the more grave defect caused by the blow of the stamp head flattening the malleable grains of gold, and driving into them hard stony particles which entirely prevent the mercury upon the copper plates from amalgamating with them.

Horse-power.—In order to find the horse-power requisite to drive a given battery, the rule is as follows: multiply the weight of one stamp by the number of stamps in the battery, by the lift in feet, and by the number of lifts per minute, and divide by sixty seconds. Allow one-third of the effective power for friction, then the effective power plus one-third of the effective power as obtained above, is equal to the number of foot-pounds per second, including the coefficient for friction. The foot-pounds per second divided by 550 give the horse-power required for the battery.

Foundations.—Owing to the rapidity of the blows and the excessive vibration caused in stamping, it is absolutely necessary to secure a firm foundation for the battery, and the usual plan adopted in ordinary ground is as follows:

The vertical mortar blocks (*a*), fig. 171, are generally of a length of

from 6 to 10 ft. sunk in a pit dug in the ground, and are well packed for 2 ft. all round with concrete, or clay and stones.

The bottom block (*b*) has a section of 18 in. × 12 in., and the mortar blocks (*a*), of which there are two or five to each five-head battery according to the size of the timber which can be obtained, are 18 in. thick and of a width equal to the length of the mortar boxes (*e*), connected together by $1\frac{1}{4}$-in. bolts, and cross timbers having 12 in. section. The tops of the mortar blocks should be slightly dished in order to prevent

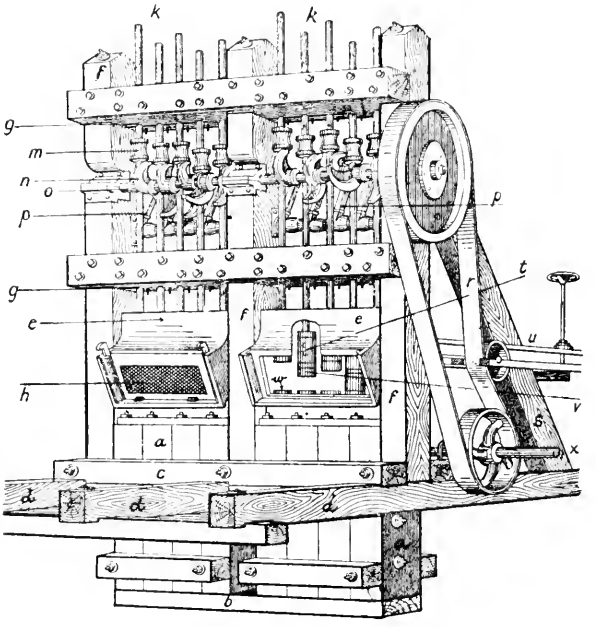


Fig. 171.—Stamp Battery: Ten Stamps.

a a Mortar Blocks. *b* Bottom Block. *c* Mud Sills. *d d* Cross Sills. *e e* Mortar Boxes. *f f* Main Posts. *g g* Guides. *h* Screens. *k k* Stamp Stems. *m* Tappets. *n n* Cams. *o* Cam Shaft. *p p* Hangers. *r* Driving Belt. *s* Brace. *t* Stamp Head. *u* Tightening Gear. *v* Shoe. *w* Die. *x* Countershaft.

them getting rounded. The cross sills (*d d*) carry the upright main posts (*f f*) and also the mud sills (*c*) the whole being strongly bolted together. It is well to put a triple layer of well-tarred blanket between the mortar boxes and the blocks, to which they are bolted down with $1\frac{1}{4}$-in. bolts.

When the ground is marshy or otherwise unreliable horizontal foundations are used which spread over a great area. The ground is dug out for from 1 to 3 ft. deep, carefully levelled, and bottom timbers,

1 ft. × 1 ft. × 18 ft., are laid parallel to the breadth of the mortar boxes, as shown at *a a a* (fig. 172), one under each upright battery post (*f f*), as

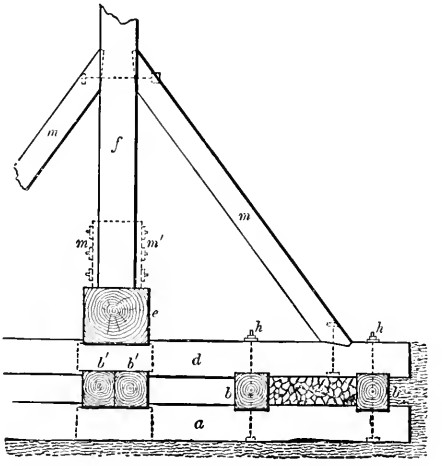


Fig. 172.—Foundations for Stamp Battery.

shown also in fig. 173. The spaces between these are filled in with shorter blocks of timber about 2 ft. long, arranged side by side under the

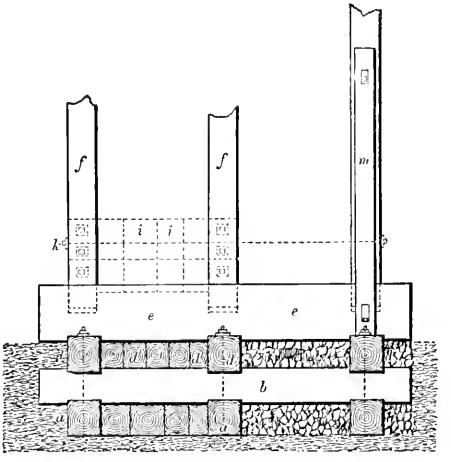


Fig. 173.—Foundations for Stamp Battery.

double cross timbers (*b' b'*), of which there are six, two being close together (*b' b'*) under the mortar block, one near each end, and one halfway between the end and the centre, as *b b*. On the top of this

floor of timber are placed other timbers similar to the lower ones, as shown in the section (fig. 172), and the spaces between the timbers, except under the mortar blocks which contain blocks of timber 2 ft. long, are filled up with stones, clay, loam, well rammed in, and the main timbers are well rolled together. The mortar block (*e*), 18 in. square, is placed on the top of this foundation, and its ends are bound with iron.

If the ground is solid rock, the bottom timbers are arranged parallel to the longer sides of the mortar box, and are let into the rock to which they are anchored by 1½-in. bolts 3 ft. long. The cross timbers are placed over these, and rest on the rock; on these the horizontal mortar block is laid, having short pieces of wood to fill up the space between the centre cross timbers.

The best material to use for these foundation timbers is, of course, oak, but owing to the difficulty of always obtaining this, pine blocks are generally made use of.

Framework.—The framework may be made either of wood, as in fig. 171, or of iron, as in fig. 181 The great advantage of wood is that it combines firmness with elasticity and can generally be found on the spot. When iron is used it is usually cast, but may be wrought, if for transport in hilly countries. Iron frames last longer than wooden ones, but the constant vibration loosens the bolts, and consequently creates trouble and difficulty.

The wooden posts such as those at *f*, in fig. 171, have a cross section of from 12 in. to 24 in., upwards to 21 in. × 24 in., and are connected together by the cross beams (*g g*) which also serve as guides to the stamp stems (*k k*). These guides are made of pieces of oak, maple, or other hard wood, and in two parts, bored at proper distances apart for the stamp stems, and being set with keys between, can be closed together as they wear.

The wooden uprights (*f f*) are braced, at least on one side, by braces (*s*) which enable them to withstand the pull of the belt (*r*). These braces may be of wood or iron, and are generally a combination of both. Iron rods of 1½ in. diameter may be used as braces, and take up less room than wood, and can be easily tightened up; the advantage of wood braces, however, is that they give greater steadiness.

Iron frameworks when used are made of hollow pillars, circular or oblong in section, or of H-shaped castings. They are fastened to separate timbers to the mortar boxes in order to lessen the vibration.

The two guides (*g g*) already referred to, are placed, the one at a height of about 3 ft. above the mortar boxes, and the other at 6 in. below the top of the stamp stem. They may be made of wood or iron, preferably the former, when their section is about 7 in. × 6 in. When they are of iron they are lined with hard wood or brass. In their more complicated

form they are made in sections capable of adjustment for wear and tear, the best known patents being those of Broughall or Fargo.

Mortar Box.—The mortar boxes (*e*) of fig. 171, were formerly made wholly or in part of wood, but are now generally constructed of cast iron, weighing each about 2400 lb. For carriage on mule back in mountainous districts the mortar boxes can be constructed in sections, which are planed, rebated, and bolted together by strong steel bolts, the top part being of wrought iron.

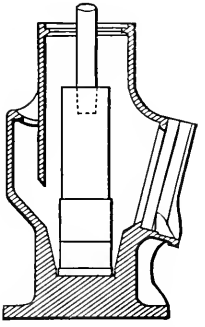


Fig. 174.—Mortar Box for Front Lining.

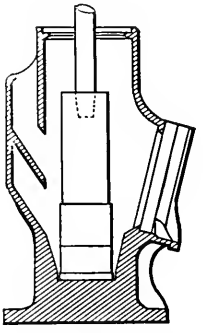


Fig. 175.—Mortar Box for Back Lining.

The usual dimensions of cast iron boxes, such as are represented in section in figs. 174 and 175, are 4 ft. high, 15 in. broad, $4\frac{1}{2}$ ft. long, the bottom being 3 in. thick; but the sides are thinner.

Fig. 175 is a single discharge box, designed for copper lining plates in the back and front, the former bolted through the mortar and the latter fastened to a block under the screen frame. The die, shoe, head, and part of stamp stem are shown at rest in the mortar.

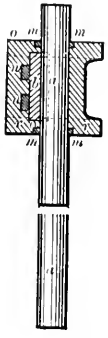
Fig. 174 is also a single discharge box, but arranged for the copper lining plate, in the front only. It is of similar construction to the other, and is peculiarly adapted for crushing base ores that must be concentrated, and need fine granulation to separate the mineral from the rock. The fineness of the pulp is regulated by that of the screens.

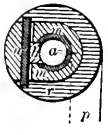
Screens.—The feed hole at the back of the box is about 3 ft. 6 in. long × 4 in. wide, placed conveniently to the feed platform. The discharge may be by overflow, or through screens, and may be single or double. The screens are made of finished or slotted sheet iron, copper, or wire gauze. See page 283, and figs. 188 to 191. Copper is better for fine holes than iron, as they do not fill up with rust. Ordinary iron screens are made of No. 22 D. W. G. sheet. They are numbered and sold according to the size of the ordinary sewing needle that will fit into the holes from No. 1. to No. 9, or according to the number of holes per lineal inch. The sizes most in use are Nos. 30 and 40, which means 30 or 40 holes to the lineal inch or 300 to 1600 holes per square inch. Punched screens of Russia iron will last on an average thirty days, but their area of discharge is not so great as with brass wire screens.

The screens are fixed in frames about 3 in. above the top of the dies, either vertically or at an angle, and a piece of canvas is hung over them, against which the pulp splashes as it passes through.

Water Required.—Each battery of five heads requires two water pipes, the quantity of water varies between 100 and 500 gallons per stamp head per hour, depending upon the nature of the ore treated.

The Stem.—The stem (*k*) of fig. 171, and *a*, of fig. 177, was formerly made of squared wood, but is now constructed of round wrought iron of from 10 ft. to 16 ft. long, and $2\frac{1}{2}$ in. to $3\frac{1}{4}$ in. diameter. The stem is turned up true in the lathe, and both ends are tapered for the last 6 in., so that either may be used as a foot. The stem has either a simple keyway cut on it, or a screw by means of which the tappet is attached.





FIGS. 176, 177. — MORTAR STEM AND TAPPET.

The Tappet is practically a cylinder of cast iron, weighing about 88 lb., 10 in. long, and 9 in. to 11 in. diameter, as shown in figs. 171 and 176, and having a central bore of the diameter of the stem.

It is slipped on the stem and fastened to it by means of a wrought iron gib (*b*) keyed up by wedges (*n n*) at right angles to the gib. The projection (*o o*) prevents the slipping of the gib which would cause an uneven wear of the cam face.

Some managers prefer the three-key tappet, but the one with two keys, as in the illustration, is most commonly used. The tappet is double ended, and can be reversed when worn down, and is easily shifted on the stem to any point which may be necessitated by the wear of the cams. Oil is not suitable for lubricating the tappets and cams, as it prevents the revolution of the stamp. It is best to use some tough grease, or a mixture of oil, tar, resin, and tallow, which turns thick on cooling. Stamp hangers (*p*), fig. 171, allow the tappets to rest on them at about 2 in. above the highest point of the cam.

The Head.—The head (*t*), fig. 171 and fig. 178, is of iron, 14 in. to 20 in. high, and of the same diameter as the shoe, say from 8 in. to 9 in. A head 16 in. high × 8 in. diameter weighs about 214 lb. In some cases wrought iron rings are shrunk on the top and bottom $\frac{3}{4}$ in. wide. The head or boss has a socket (*f*) for the neck of the shoe, the taper of both the racket and the neck of the shoe being alike. The stamp stem (*d*), fig. 176, fits into a tapering core on the head, which causes it to bind securely, needing no other fastening, and in order to facilitate the detachment of the shoe (*f*) or the stem (*d*) from the head, two channels (*m m*, *o o*) are left at right angles to each other, through which wedges can be driven in order to force off the stem or shoe when necessary.

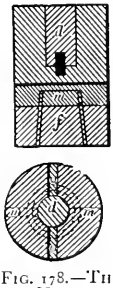
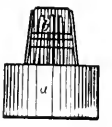


FIG. 178.—THE HEAD.

The Shoe.—The shoe (figs. 171 and 179) is mostly made of cast steel or the hardest and toughest of white iron. By means of a patent process these shoes can be cast of two kinds of iron at the same

operation; the body of the shoe is made of white iron of the very hardest quality, while the neck or stem forming the upper part of the shoe is made of iron possessing almost the tenacity of malleable or wrought iron. This combination of extreme toughness, where the strain is greatest, with exceeding hardness and durability of the parts exposed to wear, makes the patent shoes far more lasting and reliable than those made in the ordinary manner.



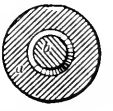
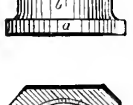


FIG. 179.—THE SHOE.

The butt is 8 in. to 9 in. long and of a diameter of 8 in. to 11 in. The shank is 6 in. high, half the diameter of the face of the shoe at the base, and $\frac{1}{2}$ in. smaller at the other end. In order to fasten the shoe to the head the shank (*b*) is surrounded with small wooden wedges held in place temporarily by a string; it is then inserted into the shank hole in the head, and afterwards a few blows are given to the top of the stem with a sledge hammer. Afterwards the head is allowed to strike a few times on the die, which is covered with a piece of wood, the battery running slowly. Ordinary round shoes weigh about 157 lb., and should not be worn down less than 1 in. from the shank. An ordinary shoe will crush about 50 tons of quartz before requiring renewal. The space between the shoes is $\frac{3}{4}$ in. The number of drops per minute may be 90, and the length of the drop 4 in. to 12 in. according to the hardness of the stone.

The order of the drop is 3, 5, 2, 4, 1; 3, 4, 5, 2, 1; 2, 4, 5, 3, 1; or 3, 5, 1, 4, 2.

The Die.—The dies (*w*), figs. 171 and 180, are made of the same material as the shoes, but of slightly larger diameter. Their weight is generally about 95 lb. The foot plate (*x*) of the die is square in shape, with rounded corners. It is $1\frac{1}{2}$ in. thick, and carries a cylindrical piece (*b*) $3\frac{1}{2}$ in. high, of a slightly larger diameter than the shoe. When worn down to the foot-plate it is replaced by a new die, which lasts about twice as long as the shoe.



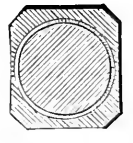


FIG. 180.—THE DIE.

Cam Shaft.—The cam shaft (*o*), fig. 171, is usually about 5 in. diameter when turned. It is of wrought iron, with two keyways at right angles to each other, and is supported on bearings let into the upright main posts (*ff*). The countershaft (*x*) is seen behind the main posts, and also its driving pulley and belt; and the tightening gear (*u*) by means of which the stamps can be stopped or put in motion without stopping the driving power.

The pulley on the cam shaft is built of wood on cast iron flanges. This is preferable to the use of a cast iron pulley, which is apt to crystallise and break, owing to the severe vibration.

The Cam.—The stamps are raised and let fall by means of the cams

(*n n*), of fig 171, which are made of cast or wrought iron, with two arms, as shown in fig. 181.

The face of the cam is from 2 in. to 3 in. wide, and the hub 4 in. to 5 in. The true shape of the cam is a modified involute of a circle, the radius of which is equal to the horizontal distance between the axis of the cam shaft and the centre of the stamp stem. The lift varies from 8 in. to 11 in., and is generally about 10 in. The friction between the cam and the tappet causes the stamp stem to revolve, and thus ensures a more even wearing of the head.

Fig. 181.—The Cam.

There are two very fine examples of stamp batteries of the Californian type just described in North Wales, near the town of Dolgelly. The one is a battery of 50 head of stamps, at the St. David's Gold and Copper Mine, driven by a Pelton wheel with a gas engine in reserve; and the other is a 40 head battery at the Gwynfynydd Mines, driven by a turbine with steam in reserve. It is interesting to note that the St. David's battery in 1900 crushed 19,463 tons of rock, yielding 13,649 oz. of gold. The total cost of mining and milling was 8*s.* 7½*d.* per ton, and the company paid a dividend of 60 per cent. per annum. The slimes or pulp after passing over the amalgamated plates are carried on to a separate building where they are treated over a series of Frue vanners, a description of which will be found on page 323. A copper concentrate carrying a little gold is formed here. The two mills are perfect in every way, and remind one forcibly of California, both by their structure and surroundings. They were built by Messrs. Fraser & Chalmers, Limited.

Iron-framed Battery.—The framework of a battery, when of wood, is usually constructed on the mine, from complete working drawings supplied by the makers of the machinery, except in those cases where there is no supply of good timber, when the framework must either be purchased with the other parts, or an iron-framed battery employed, such is that illustrated in fig. 182. The iron frames are so constructed as to be readily transported but the vibration of the stamps causes the bolts to slacken continually.

The following is a general specification of a 10-stamp battery, such as illustrated in fig. 171:

2 high cast iron mortars, of latest improved pattern, single (or double) discharge (figs. 174 and 175), planed on bottom, drilled by template, and seats for screen frames planed.

2 screen frames of soft pine wood, fitted to mortars.

4 wrought iron keys for same.

2 screens of Russia iron or wire cloth.

2 sheets of rubber for mortar foundations, $\frac{1}{4}$ in. thick.
10 stamp dies.
10 ,, shoes.
10 ,, heads or bosses, bored for stems.
10 ,, stems of refined iron, both ends tapered and fitted to heads.
10 ,, tappets, each fitted with wrought iron gib and two steel keys.

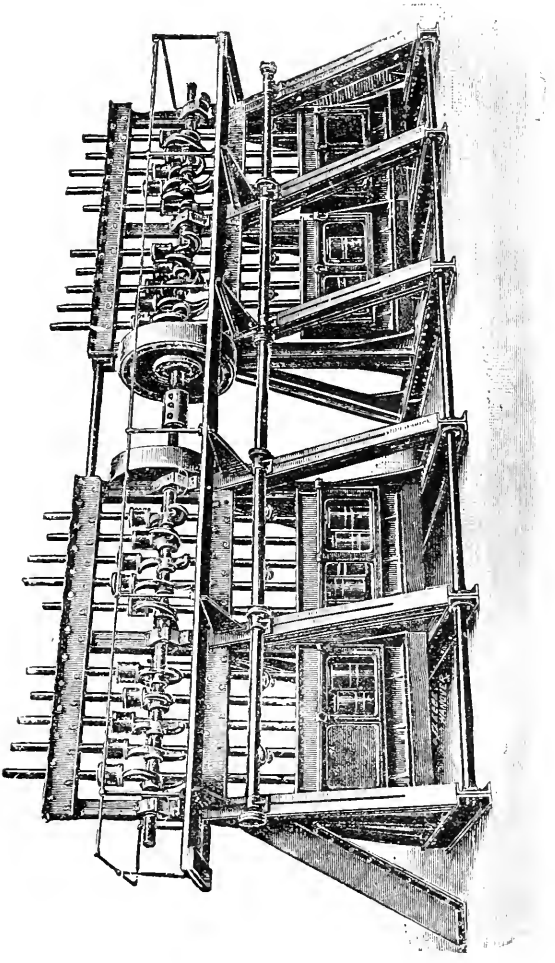


Fig. 182.—Iron-Framed Battery

10 cams, right and left hand, double lift, hubs banded and fitted to shaft with steel keys marked to place.
1 cam shaft of hammered wrought iron, turned full length, key-seated and marked where cams are fitted.
3 cam shaft boxes, babbitted, bored, and planed on bottom and back.
2 ,, ,, collars of wrought iron, with steel set-screws.

1 cam shaft pulley, built up complete on double cast iron sleeve flanges; and turned true, flanges keyed to cam shaft.
1 set upper hard wood guides for stems bored for stems and bolts.
1 set lower ,, ,, ,, ,, ,, ,, ,,
2 jack shafts of wrought iron.
4 slide boxes or brackets for jack shafts.
10 cast iron sockets for levers.
10 hard wood levers for stamp holders.

All bolts, rods, nuts, and washers for the entire framework of battery according to plans.

One set of water pipes, valves and fittings for stamps proper when mill is wet crushing.

The weight of the ironwork, including the wood pulleys and guides for a standard battery of 10 stamps, as above, would be as follows (the weight of the same material for 5 stamps being one-half those given):

10	stamps,	each	450	lb.	.	.	.	.	.	.	16,000 lb.
10	,,	,,	500	,,	.	.	.	.	.	.	18,000 ,,
10	,,	,,	600	,,	.	.	.	.	.	.	21,500 ,,
10	,,	,,	700	,,	.	.	.	.	.	.	23,000 ,,
10	,,	,,	800	,,	.	.	.	.	.	.	28,000 ,,
10	,,	,,	900	,,	.	.	.	.	.	.	31,000 ,,
10	,,	,,	950	,,	.	.	.	.	.	.	32,000 ,,

Steam Stamps.—Many endeavours have been made to improve upon the stamp battery, which is condemned by some as crude, clumsy, and wasteful; although for the actual work of crushing with a clear discharge, as in wet crushing, it is perhaps the most effective machine as yet invented. For dry crushing on certain classes of ores it is also the best machine; but here it is more in competition with various forms of pulverising mills. The great advantages of stamps are as follows: They are simple to keep in order; easy to repair by an ordinary blacksmith; generally understood; can be run almost constantly; stopped for repairs a few at a time, and so do not delay the whole mill; wearing parts are simple castings; when once erected they will last for years.

In practice they are economical, and when put up it is known that they will do their work without hitch or failure, which cannot be said of some complicated pulverisers.

An important development of the stamp battery is the steam stamp, which works upon the principle of the steam hammer, running at the rate of 90 blows per minute, and capable of crushing fine a quantity of 150 tons in 24 hours, and coarse 230 tons in the same time.

This class of stamp is illustrated in fig. 183, and is built entirely of iron and steel. The entire framing of the machine consists of four massive cast iron columns, braced to one another, and securely bolted together, and to the heavy cast iron rills or bed plates, with body-bound

bolts. This rigid structure must always remain perfectly in line, and so avoids the excessive wear and tear which a less solid type of construction would entail.

The stamp is operated by a vertical steam cylinder, which can be made of any diameter or length of stroke according to the capacity required. The shaft operating the valves by means of eccentrics and rods, is worked by a pair of machine-cut elliptical steel spurwheels,

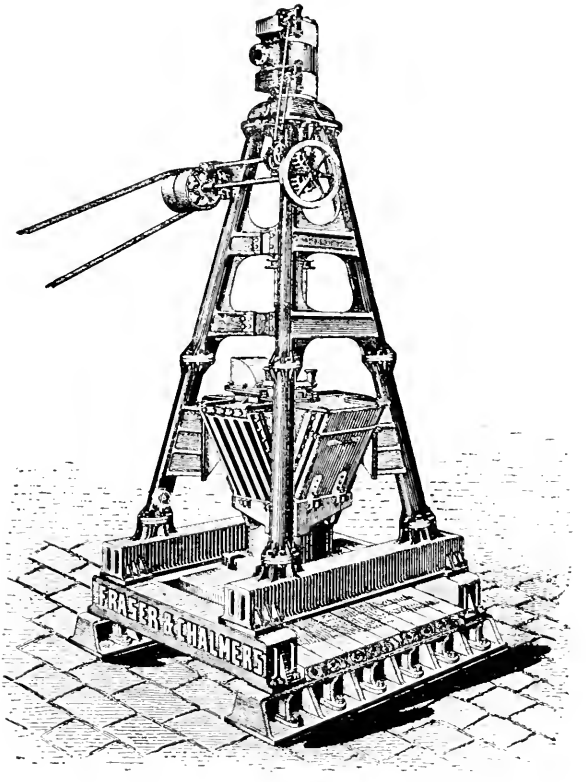


Fig. 183.—The Steam Stamp.

receiving their motion from a countershaft driven from the main mill-shafting by a belt. The object of employing elliptical gear is that the valves may be moved in such a manner as to keep the top steam port fully open for admitting the full steam pressure during the down-stroke, and a small opening of the lower port during the up-stroke.

The mortar has four discharge openings, and rests on a heavy cast iron anvil or bed plate, 20 in. thick, weighing about 11 tons, which is carried

by the spring timbers that rest upon the lower sills. Between the anvil and spring timber is a rubber cushion, 1 in. thick. The angle guide pieces cast on the columns hold the mortar in place. These guides are planed and fitted with gibs adjustable by set-screws and jam nuts. Neither mortar nor anvil are held down by bolts, and the above construction provides the necessary vertical elasticity.

The upper and lower guides for the stamp stems consist of cast iron brackets fitted with removable bronze bushings, which can be easily replaced when worn. The stamp stem is slowly revolved by means of a horizontal pulley on a cast iron sleeve between upper and lower guide brackets. This sleeve is brass bushed, and contains two feathers fitting in corresponding slots in stamp stems by which the latter is rotated.

The piston rod is made of steel, and is connected to the stamp stem by a circular disc, which is encased by a cast iron bonnet bolted to the flange of the stamp stem. The space between is filled with pure gum rubber packing. This arrangement relieves the shock on piston, and also permits removal of piston for repairs without disturbing the stamp.

Pistons are made of steel, and fitted with bronze packing rings, and are easy of access for packing and repairing when necessary. The water is fed in through the two nozzles, shown on top of mortar, and from the circular chamber is thrown against the stamp stem from every side, preventing it from being cut and worn by the sand. The ore feed, or spout, is placed on top of the mortar, and is covered over to prevent any pieces of ore from falling outside around the mortar. All bolts and studs including foundation bolts are made of the best Norway iron.

The Anaconda Company has replaced a battery of 120 stamps of 850 lb. each, by thirteen steam stamps, each having a steam cylinder of 15-in. diameter × 30-in. stroke, for the purpose of reducing copper ores to a coarse mesh, for which purpose eleven are employed, the other two being used for pulverising free melting silver ores.

The shipping weight of a 15-in. × 30-in. cylinder stamp complete with spring timbers is 140,000 lb., and the 11-in. × 22-in. stamp is 72,000 lb.

The time and expense involved in erecting a large stamp battery are often more than the original holders of a mining claim can afford. Nor indeed is it advisable to proceed to the erection of permanent plants until the properties have proved themselves worthy of it.

With the Tremain steam stamp (fig. 184), it is possible to establish a thoroughly good crushing amalgamating or concentrating plant of a moderate capacity in the shortest possible time, with the least material, and for the least money. The plant can be added to from time to time as the mine increases in prosperity, or, if need be, it can be transferred to other and more prosperous claims by simply loosening a few bolts and

disconnecting a few pipes. The cost of erection is small, while the whole plant can be put in operation within a week from delivery.

The machine is entirely "self-contained," and may be described as consisting of two stamp stems, the upper ends of which terminate in pistons, working in cast iron cylinders after the manner of the steam engine. These pistons are turned out of the solid forging which forms the stamp stems, are $5\frac{1}{2}$ in. in diameter, and are fitted with three sets of piston rings, making them steam tight. The piston rods which pass through the stuffing boxes are 4 in. in diameter, therefore, the steam pressure which is admitted under the piston to raise the stamp, is confined to an area which ; is due to the difference between the diameter of the piston and the piston rod, amounting to an annular ring about $\frac{3}{4}$ in. wide, this area is small, but sufficient to quickly raise the stamps, the total weight of which is but 300 lb.

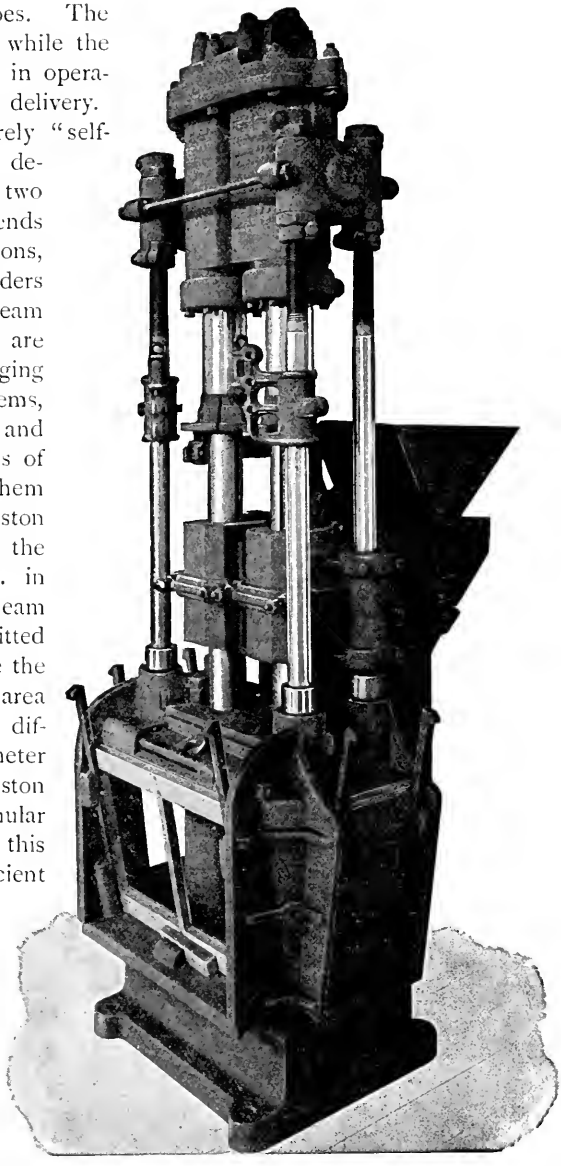


FIG. 184.—THE TREMAIN STEAM STAMP.

Either piston in its travel toward the top of its cylinder passes a small steam port, which admits the pressure to the valve mechanism and moves the valve to its opposite position, the movement of the valve cuts off the admission of steam to the underside of the piston, and admits to the underside of its mate, at the same time connecting the top and bottom ends of the first-mentioned

cylinder together, thus allowing the confined steam which is holding the stamp up, to be expanded around the piston to its upper side, and acting expansively upon the large area there encountered, to so energetically assist the 300 lb. stamp in its downward movement as to strike a blow upon the die equal to that of an 800 to 1000 lb. gravity stamp.

The pistons alternate with each other perfectly, and when the valve is moved back to again admit steam to the underside of the first-mentioned piston, it also connects the top side with the exhaust port, so that the steam remaining after the blow has been struck is passed into the atmosphere. This arrangement makes it possible to use the steam expansively, and to obtain the same crushing effect with each drop of a 300 lb. stamp as would be obtained with a gravity stamp of 800 to 1000 lb. dropping 8 in. (depending upon the pressure used). Instead of being limited to about 90 drops per minute, as with the gravity stamp, is obtained a speed of 200 or more drops per minute of each stamp, and it will be obvious that the crushing capacity must be correspondingly increased.

No Framework Required.—The machine is complete in itself, weighs but 3300 lb. and, being built entirely upon the mortar, it requires no framework of any kind in its erection other than a substantial mortar block.

Capacity and Screens.—The capacity of the mill will vary much according to the character of the ore, but may be put at from 8 to 18 tons of ordinary gold ore through a 40-mesh screen in 24 hours. The screens have an area of 540 sq. in., and because of the very rapid movement of the stamps a much greater agitation on the mortar is kept up, and, consequently, a much greater height of screen surface is made available for the discharge of the pulp. The mill is provided with silver plated tip plates on the mortar, which take the place of inside coppers, and are a perfect index of the conditions inside the mortar and for feeding quicksilver.

Power.—The power required is a 10 horse boiler, but as a 15 horse boiler would permit of the stamps being run at a greater speed and would only entail a slightly increased cost, this size would perhaps be preferable. The boiler should be placed as near as possible to the stamps. The speed of the machine is variable at will, being a matter depending entirely upon the pressure used. Approximately it is as follows: With 60 lb. pressure, 140 drops; with 80 lb., 180 drops; with 100 lb., 200 drops per minute of each stamp, etc. Increasing the pressure increases the speed, and *vice versâ*.

It is customary to carry about 100 lb. pressure at the boiler, and maintain a speed of about 200 drops per minute.

Imperfections of Stamp Batteries.—Although the use of stamps is very general, and the machine has justly become popular, it must not be concluded that it is the most perfect appliance for crushing gold quartz; all that can be said is that it holds its own in the front rank of the numerous inventions which have been brought before the public for that purpose.

The great desideratum for the object in view is a machine which will liberate the atoms of gold from their matrix of quartz or other gangue without destroying them, just as the kernel of a nut is freed from its shell by the nut-crackers. As yet no appliance has been invented which will stop short at this point, and the consequence is, that in stamping, the atoms of gold are crushed up and flattened, and by the continued blows beaten out into thin films, into which hard stony particles are driven. The effect of this is that the gold is either so finely divided as to float away with the water, or that the flattened grains are hardened by the repeated blows, and coated with a film of gangue or other impurity, which effectually prevents their being attacked and retained by the mercury of the amalgamated plates.

Such is the effect upon the gold, but another and very serious imperfection, common to most pulverising machines, is that, after crushing the ore down to the requisite size, they keep on pulverising it down to the state of the finest slimes. This is especially noticeable with regard to a stamp battery, as it is necessary to keep the mortar box filled with a sufficient quantity of water to keep the whole of its contents in motion. When the blow of a stamp is struck it creates a small quantity of fine material, and this, instead of being carried away at once, is drawn back upon the die by the suction caused by the raising of the stamp, and so is again pounded when already reduced to a sufficiently fine state.

This action continues indefinitely, so that the pulp finally issuing from the screens contains mineral in all degrees of fineness, from that of an impalpable powder up to the size of the mesh of the screen. Numerous experiments have proved this, and the following are the results of one made in Australia upon pulp which had passed from the battery through a 25-mesh screen.

The size and percentage of the crushings * were as follows:

Grains $\frac{1}{50}$ inch diameter		12 per cent.
,, $\frac{1}{50}$	,,	31 ,,
,, $\frac{1}{72}$	,,	10 ,,
,, $\frac{1}{100}$	,,	47 ,,

From the action of the stamp battery everything tends to show that had

* *Engineering*, August 26th, 1887.

the experiments been proceeded with further, much of the 47 per cent. would have been divisible to diameters of as small as 400 or even 500 to an inch.

The direction in which inventors should seek to improve all pulverising machines used for amalgamation purposes is sufficiently evident from the above experiment. Classification is of the utmost importance in coarse concentration, as will be found explained in Chapter XIII. If anything it is of still greater importance in fine concentration; and the machine which will liberate the gold without creating valuable slimes is the one which will ultimately take precedence of all others for milling purposes. For roasting and leaching, however, the reverse is the case, as it is an advantage here to have the ore particles very fine, and the gangue coarser, so that, seeing that rolls produce a more even grain and less diversity of size than stamps, it would appear that some form of roller crusher would be the more advantageous for pulverising previous to amalgamation, while stamps are preferable when the ore has to be roasted.

A table showing the quantity of water and the power required for various mills will be found on page 471.

CHAPTER XIII.

SIZING AND CLASSIFICATION TROMMELS.

Sizing—Classification—Grizzlies—Shaking Screens—Trommels—Rittinger's Scale of Classification—Screens or Perforated Plates—Hydraulic Classifiers—Spitzkasten—Slope of Water Channels.

It may be taken as established that the success of any process of concentration depends upon the exactness with which the grains of mineral have been previously sized and classified, and it is largely owing to the extreme care exercised in Germany that these two operations are carefully carried out, that the Germans owe their renown as ore dressers.

Sizing.*—Sizing consists of passing grains of ore through a sieve, by which a group of grains is obtained of an approximately equal volume, but of different densities. This is volumetric sizing.

Classification consists of subjecting grains of different densities to the action of a current of water, when a group of grains differing in their volumes, but having equal velocities of fall, are obtained. These grains may be termed equivalents.

The *volumetric* sizing of an ore is effected by means of sieves or trommels, the result being to divide the ore into different groups, having grains of equal volume but of different densities according to their specific gravities, which, when falling through water, will separate from each other, owing to the different speeds at which they will fall. These grains are concentrated in jiggers.

The *classification* of the fine grains of ore is carried out in hydraulic classifiers, pointed boxes, spitzlutten, and spitzkasten, the result being the production of groups of grains of ore, which will differ from each other in volume and density, but will fall in a current of water with equal velocity, and group themselves at the bottom. The separation of the rich from the poor in such grains having an equal velocity of fall in water is effected by taking advantage of the greater resistance which the grains of large diameter will expose to a washing current of water, as on a buddle or vanner, in comparison to the smaller diameter and greater

* "British Mining," by Robert Hunt. London: Crosby Lockwood & Son.

weight of the richer grains of lesser diameter. The former will move with greater rapidity than the latter, and a separation of the two will thus be effected.

The importance of insisting upon a careful sizing of the ores will be evident from a study of the following table, showing the fall of spheres in water in one second of time, all being in millimetres:

Diameter in Millimetres.	Gold, Sp. Gr. 19·2 Millimetres.	Galena, Sp. Gr. 7·5 Millimetres.	Blende, Sp. Gr. 4·0 Millimetres.	Quartz, Sp. Gr. 2·6 Millimetres.
17·43	2614	1570	1066	780
11·32	2197	1320	898	653
8·71	1849	1110	750	550
6·16	1569	935	624	461
4·36	1307	785	514	385
3·08	1097	660	448	326
2·17	840	555	378	275
1·54	780	465	317	231
1·08	653	393	266	194
0·77	548	327	210	163
0·54	456	275	188	137

From this table it will be seen that the grains of various metal fall through water at rates of speed varying with their diameters; thus a grain of gold ·77 mm. diameter will fall through 548 mm. of water in exactly the same time as a grain of quartz of 8·71 mm. diameter, or a grain of galena ·54 mm. diameter will fall through 275 mm. of water in the same time as a grain of quartz of 2·17 mm. diameter. If, however, the grains have been previously sized to equal diameters we have a result which renders their separation possible. Thus a grain of galena of 4·36 mm. diameter will fall through 785 mm. of water in the same time that it takes a similar grain of quartz to fall through half the distance, or 385 mm. and so with the other minerals. It is evident, however, that the velocity of the fall of the grains depends not only upon their specific gravity, but upon their bulk and gravity combined, and that for a perfect separation of substances according to their gravity, it is essential that the particles should be as nearly as practicable of the same size.

It is the above principle which is made use of in jigging, and as it is impossible to have a drop long enough to separate the particles at one blow, we must obtain the requisite drop by repeating the number of the short perpendicular blows. Before, however, we consider the construction of a jigging machine, we must, first of all, study the arrangements by which in practice the division of the mineral into sizes is obtained.

The ore as it is blasted down in the mine is of all sizes, from the inconveniently large, which has to be broken up with a sledge hammer, to the fine dust which, if the ore is rich, must be swept up with a broom. To some extent the ore is sorted in the mine, where the sterile gangue

is roughly picked out and left to support the roof, or the walls of the worked-out lode. The transport of worthless stuff to the surface being thus avoided, in cases where the ore is sufficiently rich it may be put in bags underground so as to prevent loss. On being brought to the surface the ore may be hand-picked over, previous to being sent to the mill; but the general rule is to send it on direct, and it is tipped over a sloping screen of iron bars called a grizzly, or a perforated iron plate, and here the first operation of sizing may be said to commence. The general arrangements of a concentrating mill will be found explained and illustrated by diagrams in Chapter XXV., page 444.

Grizzlies.—The screen or grizzly is made of iron bars from 8 ft. to 9 ft. long, set in a wooden frame fixed at an angle of 45°. The bars may be fixed at from 1 in. to 2 in. apart, according to the class of ore. The coarse stuff is sent on to the stone-breaker, and then rejoins the fine and passes to the stamps in the case of gold, silver, or tin ores, and some through a sizing trommel having holes of $\frac{1}{2}$ in. to 1 in. in the case of lead, copper, and zinc ores. The coarse from this is fed on to a picking table where the rich as well as the poor waste ore is taken out, and then it passes through a roller crusher, after which it rejoins the fine, and the final sizing, before it is sent to the jiggers and concentrating machinery, is effected, in a series of trommels or rotating circular sieves covered with perforated sheet metal or wire gauze. Formerly flat shaking sieves were employed for the sizing of the ores, but the general practice is now to use circular trommels.

Shaking Screens.—Although the trommels about to be described are the best appliances for sizing the ore, yet I have used suspended shaking screens for the purpose of getting rid of the slimes and dirty water

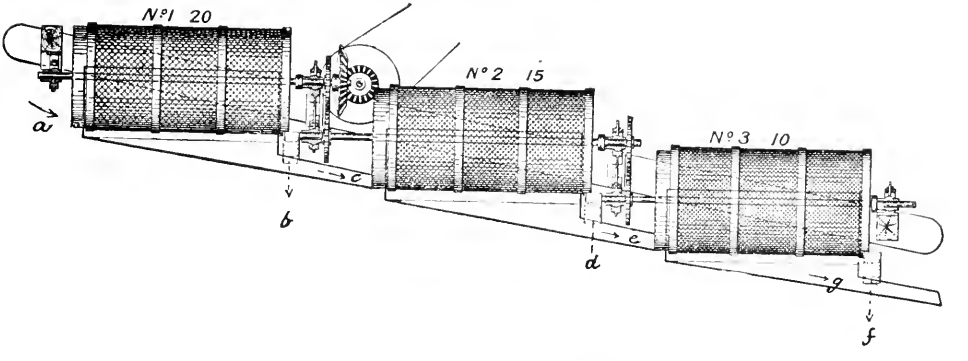


FIG. 1185.—REVOLVING SCREENS FOR WET SIZING.

before sending the crushed ore into the sizing trommels. The mill where

I used these screens is described on page 455 (fig. 302). The screens here served the double purpose of rejecting the ore too coarse for concentration and sending it back direct to be recrushed, thus relieving the trommels, and also of separating out the fine ore and slime waters, thus keeping the ore for the coarse jiggers clean and so facilitating concentration. The screens are simply perforated steel sheets in a wooden frame which is suspended on wooden laths and caused to shake by means of a connecting rod at each end driven from a fast running crank-shaft.

Trommels.—The usual arrangement of a set of trommels will be seen in fig. 185, each trommel being placed in the same line below the other, the number of trommels depending upon the number of sizes into which the mineral is to be divided. In some cases the trommels are placed side by side, parallel to each other instead of end to end; but in either case each one must be on a different level, so as to allow the ore to pass from one to another. The trommels may be made cylindrical, as in fig. 185, or conical, as in fig. 186, which is a compound trommel having an inside screen of perforated sheet metal and an outside one of wire gauze, thus screening to two sizes at one operation. In the case of cylindrical trommels the shaft must be inclined so as to allow the mineral to progress through without blocking, but the shaft of conical trommels may be level, as the angle of the screen allows for the onward motion of the ore.

In the set of trommels shown in fig. 185, the ore from the crusher enters at *a*, and the coarse ore for recrushing travels through the trommel and out at *b*, to be sent back by means of an elevator. Assuming that this trommel has holes of 20 mm. diameter the whole of the mineral passing through there goes on to No. 2 trommel by the shoot (*c*). This trommel has holes of 15 mm., and consequently rejects all ore above that size, which falls down the shoot (*d*) and is fed on the coarse jigger destined for treating all stuff between 15 and 20 mm.

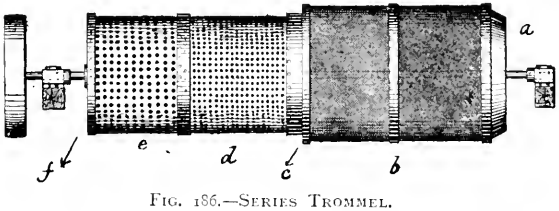


FIG. 186.—SERIES TROMMEL.

The ore under 15 mm. passes through the screen, and by the shoot (*e*) to the trommel, No. 3 having holes of 10 mm. In this all ore over 10 mm. is rejected at *f*, and goes to the jigger, which treats ore between 10 and 15 mm. The fine stuff passes through the mesh and on by the shoot (*g*) to another trommel, and so on down to 1 mm. holes, after which the further operation is one of classification by means of water.

Sometimes the space and fall will not allow of the trommels being thus arranged in a cascade, and in such a case the operation, instead of proceeding from coarse to fine, is reversed, and goes from fine to coarse, the whole of the rough ore falling first upon the fine sieves, an arrangement which, if possible, should be rigorously avoided. When these conditions are a necessity, a long continuous trommel, such as the one in fig. 186, is employed. The ore enters at *a* and falls upon a screen, say 2 mm. diameter, through which the fine stuff passes, and is again divided by the outer screen, having holes of 1 mm. The slimes under 1 mm. thus comes through *b*. Those between 1 and 2 mm. are rejected at *c*, and the coarse ore inside the main trommel passes first over *d*, when the stuff over 4 mm. is separated, and then over *e*, where the holes are 6 mm., the remainder is rejected at *f*, either for recrushing or to go on to a larger trommel. The grave inconveniences of this form of trommel are, 1st, that the whole of the ore passes over and rapidly destroys the fine screens; and 2nd, that, owing to the length of the shaft, it is almost certain to bend and sway under the weight of the ore, entailing great wear and tear and a short life for the whole system. In some cases it is impossible to avoid the use of a double trommel, as in fig. 187, but this form, by covering up the inner screen, prevents any small repairs being done to it, which, when left to accumulate, soon involve a serious evil.

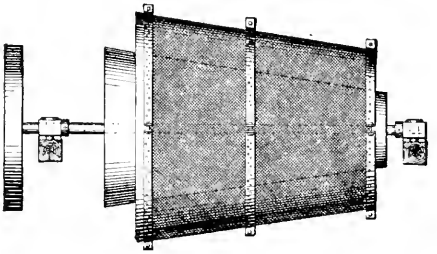


Fig. 187.—Conical Trommel.

In order to prevent the holes from clogging up with mineral, a strong spray of water is allowed to play upon each trommel, and in some cases wooden beaters are arranged so as to tap the sieve automatically and thus free the holes. The water spray is to be preferred.

The question as to the sizes of the holes in the trommels is one which varies according to the ore to be concentrated, and is best decided by actual experiment at the trial works of the makers of the machinery when the type of machines is also under consideration. As a general rule the mineral to be treated should only be reduced to that size which will allow of the separation of a portion of the ore contained, or of the steriles, if these be in a large proportion, so that when the ore occurs in grains of large size these may be jigged out without having to be crushed down to powder, a process which always means loss. The crushing, in short, should be limited to that sufficient to free the grains of ore from the gangue. The holes in the trommels, therefore, must be based upon this—the largest holes being those which will allow the freed uncrushed

grains of ore to pass through them. The rich product being thus separated, the recrushing of the mixed mineral and tailings is again guided by the same principle, viz., that of freeing the grains of ore from the gangue by crushing, but without pulverising them.

As an example of the sizes of the holes in the trommels of a lead mill, we have those in use at the Linares Mill in Spain, of which a description is given on page 445. The holes in descending order are 22·6 mm., 16, 8, 4, 2, 1 mm., below which a classifier is used which feeds four jiggers, and after that a spitzkasten for the finest slimes sent to the Linkenbach tables.

On page 446 will also be found the description of the trommels employed at the Neuhof Mine in Silesia, and on page 445 the details of the mill which I erected at the Cwmystwith Mine.

Rittinger * adopts 1 mm. in diameter as the unit of holes for sizing ores for concentration, and the progression beyond this is geometric, as 1, 2, 4, 8, 16 mm., giving for the volumes of the grains, which will pass the holes respectively, 1, 8, 64, 512, 4096 cubic mm. He divides each of these sizes of holes into four classes each with four grades, thus:

	Diameter in Millimetres		In Inches nearly.	
No. 1. Rough Stuff	64·0	=	2·51	Coarse.
	45·2	=	1·79	Middling Coarse.
	32·0	=	1·26	,, Fine.
	22·6	=	0·89	Fine.
No. 2. Coarse Stuff	16·0	=	0·64	Coarse.
	11·3	=	0·45	Middling Coarse.
	8·0	=	0·319	,, Fine.
	5·6	=	0·220	Fine.
No. 3. Coarse Sand	4·0	=	0·160	Coarse.
	2·8	=	0·109	Middling Coarse.
	2·0	=	0·078	,, Fine.
	1·4	=	0·055	Fine.
No. 4. Fine Sand and Slime	1·00	=	0·0400	Coarse.
	0·71	=	0·0282	Middling Coarse.
	0·50	=	0·0200	,, Fine.
	0·35	=	0·0137	Fine.

There can, however, be no fixed rule for the sizes of the holes as each separate ore will require an arrangement differing according to the friability of the mineral and its distribution in the gangue.

For fine concentration, as in the case of gold, silver, tin, and sometimes copper ores, no trommels are needed, as the slimes or pulp go direct from the stamps to a hydraulic classifier in the form of a V-shaped box, or spitzkasten, from which the thickened and classified slimes are led either to fine slime jiggers or direct to the vanners or buddles.

* "British Mining," by R. Hunt.

Screens or Perforated Plates.—The subject of perforated screening plates is closely associated with that of trommels, and can advantageously be referred to here before leaving the subject of the "sizing" of ores for that of the classification of sands and slimes previous to concentration.

The material of which the perforated plates is made is Russia sheet iron, charcoal iron, or sheet steel for the larger holes, or sheet copper and wire gauze for the smaller. The plates of the coarse washing trommel, which are subject to rough usage, can well be made of boiler plate with

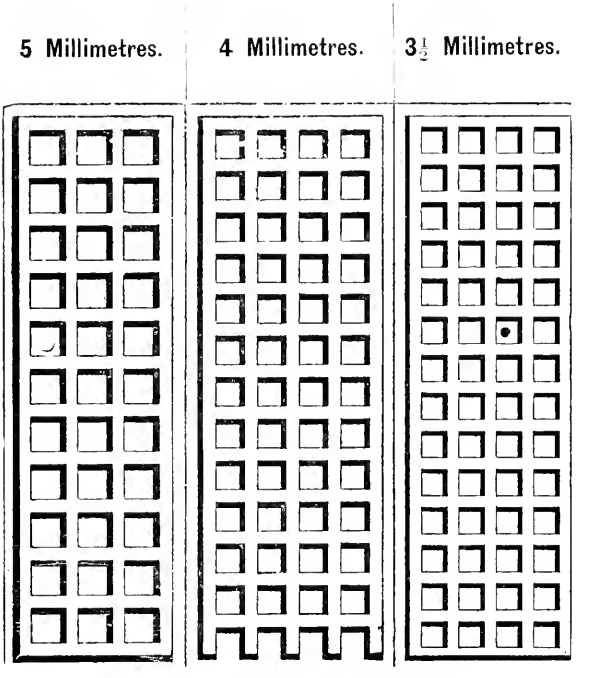


FIG. 188.—SCREENS FOR TROMMELS AND JIGGERS.

the holes drilled through. Steel wire netting has also been tried for this purpose, but my own experience is in favour of the boiler plate. The mesh of the steel netting soon becomes torn and irregular; for work in a less exposed position it can, however, be used, while gauze of steel wire can also be employed instead of the copper gauze.

The thickness of the plates varies according to the diameter of the holes. Copper plates are preferable for the finer meshes, as the iron ones are liable to rust up, and the holes can be punched of a conical shape.

The size of the holes may be quoted in millimetres, as is the continental method, or by the number or size of a sewing needle which will

fit the hole of the screen, or the width of the slot if slotted plates are preferred.

For battery screens the number of holes per lineal inch is given. The holes in the plates should always be punched, and the roughened side left by punching turned inwards to meet the wear of the pulp or slimes. In stamp batteries it is estimated that each head of five stamps will

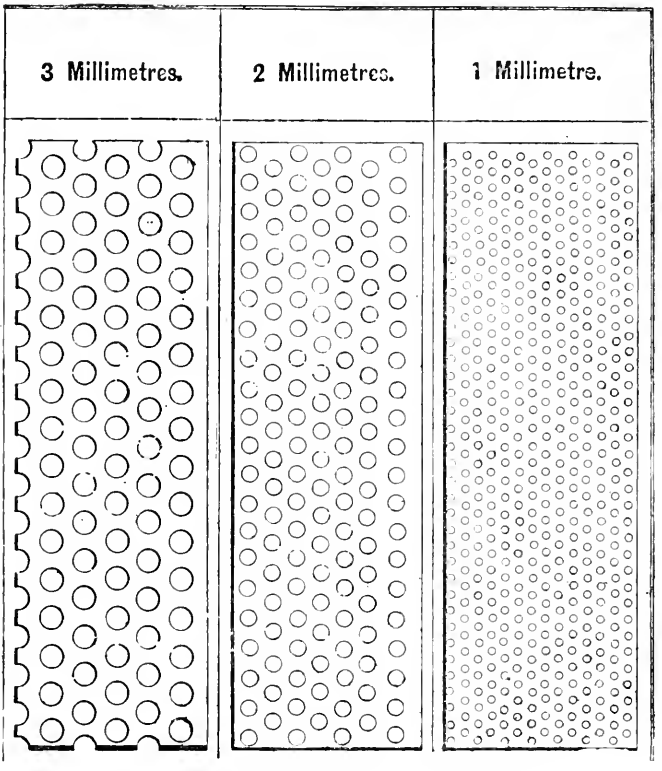


Fig. 189.—Screens for Trommels and Jiggers.

require thirteen sets of screens per annum, each set consisting of five sheets of 1 to 1½ sq. ft.

One of the difficulties with the screens forming the bottom of jiggers of a fine mesh is, that they are liable to get clogged. In order to mitigate this nuisance, if not entirely to cure it, I have been in the habit of using copper screens punched with conical holes, the wider end being placed downwards. For jigging ore under 2 mm. these screens certainly give better results than those of the ordinary type.

For trommels and the beds of jiggers the holes may be round or

square, as shown in figs. 188 and 189. The slotted plates used for stamp batteries are shown in fig. 190, and the steel wire and fine brass wire, or copper screens, also used in batteries, are shown in fig. 191.

TABLE FOR PUNCHING ROUND HOLES IN IRON AND STEEL.

DIAMETER OF HOLE.		THICKNESS WHICH CAN BE PUNCHED.		IRON.
Inches.	Millimetres	Iron—No. Gauge.	Steel—No. Gauge.	Weight Sq. Ft.
—	$\frac{3}{4}$	26	28	0·8
—	1	24	26	1·0
$\frac{6}{100}$	—	22	24	1·25
$\frac{1}{16}$	$1\frac{1}{2}$	20	22	1·5625
—	2	18	20	1·875
—	$2\frac{1}{2}$	16	18	2·5
—	3	14	16	3·125
$\frac{1}{8}$	—	14	16	3·125
—	$3\frac{1}{2}$	13	15	3·75
$\frac{5}{32}$	—	12	14	4·375
—	4	12	14	4·375
—	5	10	12	5·625
$\frac{7}{32}$	$5\frac{1}{2}$	9	11	6·25
—	6	8	10	6·875
$\frac{1}{4}$	—	6	8	8·125
—	7	6	8	8·125
—	8	4	6	9·375
—	9	4	6	9·375
$\frac{3}{8}$	—	3	5	10·0
—	11	3	5	10·0
$\frac{1}{2}$	$12\frac{7}{10}$	2	4	10.625
1	$25\frac{2}{5}$	1	2	11·25
$1\frac{1}{2}$	$38\frac{1}{10}$	1	2	11.25
2	$50\frac{4}{5}$	1	3	11.25
$2\frac{1}{2}$	63	2	4	10·625
$2\frac{3}{4}$	$69\frac{8}{5}$	2	4	10·625
3	$76\frac{1}{5}$	2	4	10·625

TABLE FOR PUNCHING NEEDLE SLOT SCREENS.

No.	Mesh.	Width of Slot.	Russian Gauge. Thickness.	Equivalent Birmingham Gauge.	Decimal of an Inch.	Weight per Square Foot.
1	12	·058	15	$22\frac{2}{3}$	·0269	1·24
2	14	·049	15	$22\frac{2}{3}$	·0269	1·24
3	16	·042	15	$22\frac{2}{3}$	·0269	1·24
4	18	·035	15	$22\frac{2}{3}$	·0269	1·24
5	20	·029	14	$23\frac{1}{4}$	·02425	1·15
6	25	·027	13	24	·022	1·08
7	30	·024	12	$24\frac{1}{2}$	·021	0·987
8	35	·022	11	25	·020	0·918
9	40	·020	10	26	·018	0·827
10	50	·018	9	27	·016	0·735
11	55	·0165	8	28	·014	0·666
12	60	·015	8	28	·014	0·666

The greatest thickness of iron or steel which can be punched with round holes, and the weight of the plate per square foot is given in the tabular statement. The price varies with the thickness of the plate, but in most cases this can be less than that given in the table.

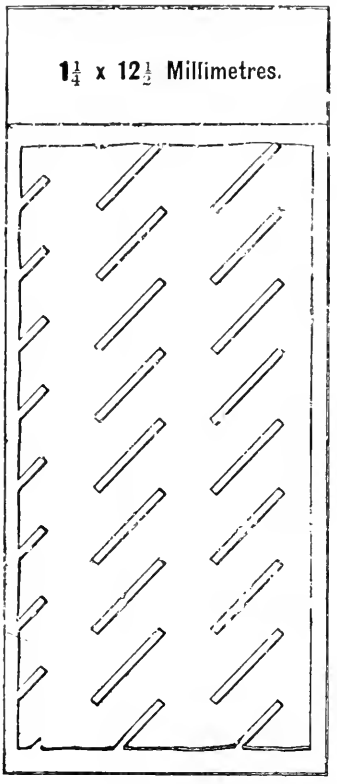


FIG. 190.
SLOTTED SCREEN FOR BATTERIES.

The slots in the battery screens (fig. 190) are usually set diagonally as shown; but screens can be obtained in a great variety of patterns, and either in iron, steel, or copper, as may be required.

The difficulty with iron or steel screens is their liability to rust if the mill is stopped for a short time. On the other hand, copper screens, while more durable, are far more expensive, and can only be used for the finer sizes.

Fine Classification. — We have seen how the coarser grains of ore are sized by means of trommels and screens into groups of grains of equal volume, and now have to deal with the finer grains, which cannot be handled in trommels, but must be classified, not according to their volume and density, but according to the rate at which they will fall through a given depth of water as already explained.

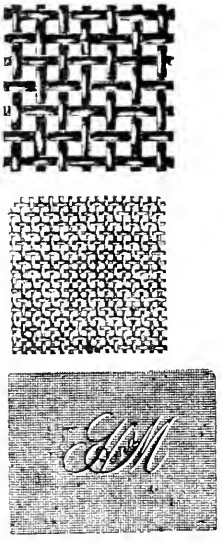


FIG. 191.
WIRE CLOTH SCREENS.

An hydraulic classifier for carrying out this principle, is shown in figs. 192 to 193, which are reduced from actual drawings of an apparatus which I once constructed, and successfully used of this kind, the original drawings being supplied by the firm of German machinists who supplied the machinery. The classifier supplied the mineral to two five-compartment percussion lever jiggers. The slimes which arrived at the smaller or inlet end, shown by the arrow on the plan (fig. 192), spread themselves out with gradually decreasing velocity, the heavier and larger

particles falling first, the lighter and finer being carried on until only the finest slimes escaped at the exit and went to the spitzkasten, where they were thickened previous to treatment on the Linkenbach tables.

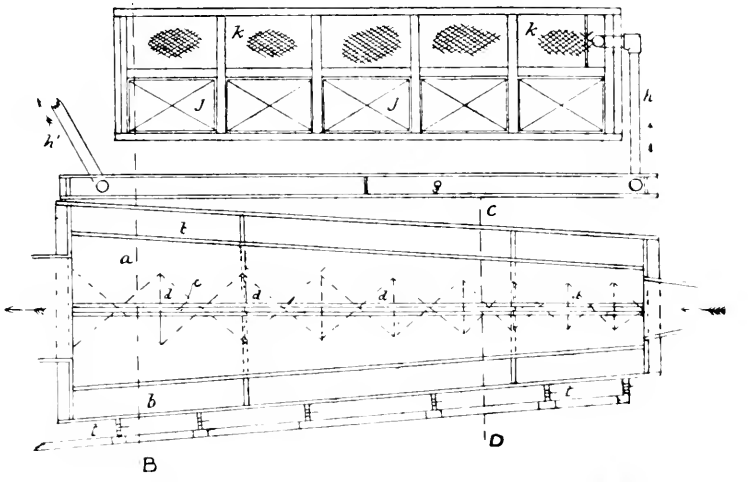


Fig. 192.—Plan of Hydraulic Classifier. Scale 15 mm. = 1 Metre.

The classifier is built of either wood or sheet iron. Fig. 194 is a section at the upper and smaller end, and fig. 195 is the section at the further and larger end. A is a smooth inner casing gradually expanding

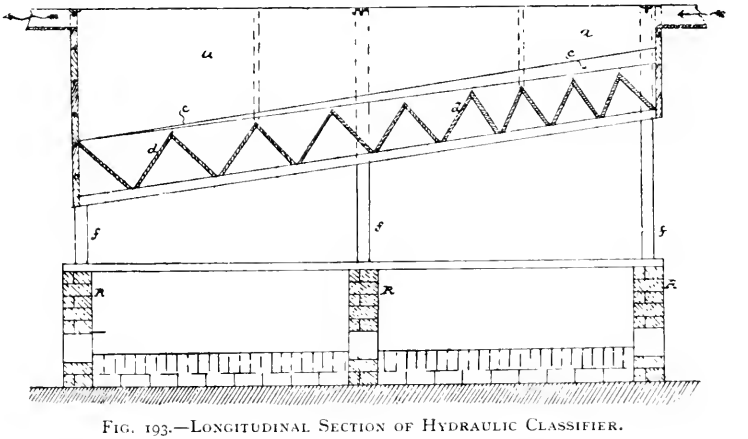


Fig. 193.—Longitudinal Section of Hydraulic Classifier.

and deepening, and having a slot (*c*) at its apex about $\frac{1}{4}$ in. deep running the whole length. B is the outer casing, divided longitudinally under the inner casing (*a*) by angular divisions (*d*) from the points of which the

pipes (*e*) convey the classified mineral to the trough (*g*) on the outside of the classifier, and at a distance of 500 mm., or, say 19 in., below the surface of the water inside. Fresh water is conveyed into the classifier by means of the tap (*t*) and this, by keeping the level of the water higher in the outer casing (*b*), causes a constant upward stream of water to flow through the slot (*c*), checking the tendency of the mineral particles to deposit themselves, and separating them into several groups. The plans are drawn to scale, so that where the dimensions are not given they may readily be obtained.

The classifier is elevated upon a brick foundation (R) which is divided into small reservoirs or cases, which received the slimes which fall from the pipes (*e*) when they are opened for cleansing purposes.

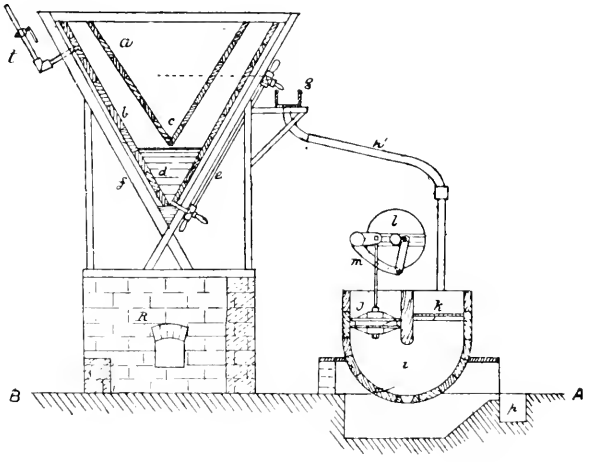


FIG. 194.—CROSS SECTION OF HYDRAULIC CLASSIFIER.

The jiggers which treat the classified mineral may either be quite near, as shown in figs. 194 and 195, or at any convenient distance provided that there is fall enough to convey the rich thick slime through the pipe (*h'*).

In the cross-section (fig. 194) *i* is the jigger, fixed on a concrete bed, in which the receiving case (*o*) is formed for the reception of the enriched products. The excess water flows away by the channel (*p*). The disc (*l*) is fixed on the driving shaft, and carries a crank pin, whose stroke may be varied according to its position in the slot on the face of the disc.

A short connecting rod is placed between the crank pin and the lever (*m*) which causes the pulsation of the piston shaft, and through it and the piston rod operates the piston (J).

The effect of this system of lever is that the down-stroke of the piston is rapid, and the up-stroke slow.

As an appliance for classifying the fine sands, the hydraulic classifier is most efficient, and requires but little attendance beyond the care necessary to prevent the pipes becoming choked with sand. It will be noticed that wooden plugs are inserted at all the angles, and these admit of the pipes being cleared by means of iron rods. The supply of fresh water must be so regulated as to be sufficient to drive off the slight slimes, but not so strong as to carry away the coarser sands. There are many forms of hydraulic classifiers built on the above principle. The example given is large enough to supply two or three jiggers, and may be extended at either end by following the general lines given, preserving the same inclination and angles.

When in Nevada, in 1900, I saw an hydraulic classifier, similar to that just described, used instead of trommels for sizing ore from $\frac{1}{2}$-in. mesh downwards. The only difference being that, in order to obtain sufficient water pressure to lift the coarse grains, the space between the inner and outer cases (*a* and *b*), figs. 194 and 195, was closed at the top, so that the pressure of the water arriving at (*t*) could be brought to bear on the mineral. For coarse ore also the pipe (*e*) is suppressed, the mineral flowing direct from the bottom of *d* to the jiggers. The essential point in using this type of classifier is that the water pressure must be constant, otherwise classification cannot take place. Hydraulic classifiers are much more simple and easier to keep in repair than a set of trommels; but, on the other hand, they require more careful attention in order to obtain good results. They are made of various designs, and may be simply cast iron or wooden V-shaped boxes, with a pipe from the bottom to convey the ore to a jigger and another one conveying clean water under pressure, which also arrives in the bottom of the V and drives over the lighter particles while the heavier fall past it and into the jigger or other concentrator. A very convenient type of classifier in cast iron, with taps to regulate the supply of water, is made by Messrs. Green & Sons, of Aberystwith, Wales, which I have used very successfully for classifying galena and blende ores.

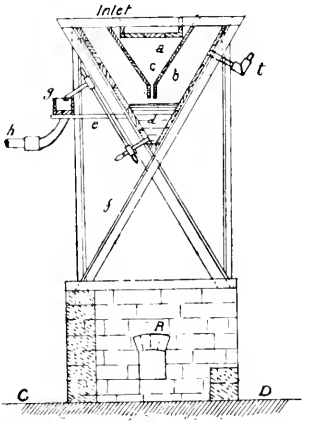


FIG. 195.—CROSS SECTION OF HYDRAULIC CLASSIFIER

Spitzkasten.—The fine slimes rejected by the hydraulic classifier flow on to a spitzkasten, an apparatus consisting of funnel-shaped boxes or rectangular pyramids with the base upwards, in which the sands settle, the coarsest in the first, and the finer in the second, and so on for the series.

The position of the classifier and spitzkasten are shown at *u* and *v* in Plates X. and XI., and at L and V in Plates XII. and XIII., as well as in fig. 220, where it is seen immediately behind the Linkenbach table to the right. It consists essentially of a large wooden V-shaped box about 8 yds. long and 3 yds. wide, divided longitudinally into the shape of a W, the middle portion of which is not quite so high as the outside arms; the inclination of the long sides being an angle of 50°, which is sufficient to prevent the slimes from accumulating on them. The slime waters are spread over the surface of this, the heavy particles fall to the bottom, and the light muddy waters flow away to the settling pits outside the mill.

From the points of the pyramids two pipes, as inverted syphons, lead up to a trough fixed on the outside of the spitzkasten, at a level of about 2 ft. 6 in. to 3 ft. below that of the water on the inside. From this trough a pipe leads to the Linkenbach tables, and through this the thickened slimes flow to be enriched.

The large spitzkastens, used for thickening the slime waters at the Cwmystwith mill are shown in Plate XX. (p. 458). I have found it advantageous to lead the pipes, say from three of the divisions of the big spitzkasten, into a channel conducting the joint slimes from the three pipes into a small classifying spitzkasten placed between the main one and the head of the vanners. Thus the main spitzkasten thickens the slimes, while the smaller ones of which there is one for each three divisions, classifies the slimes and feeds them on to a pair of vanners.

The waste water from the end of the spitzkasten is usually taken over a series of slime pits, so as to allow of any mud or mineral matter being deposited. If water is scarce the overflow from the slime pits can be pumped back again to the mill and used over again. The loss in water is usually 25 per cent. of its bulk.

Slope of Channels.—It is very important that all the troughs and pipes conveying water charged with mineral should have an inclination sufficient to prevent their being choked. This should not be less than 1 in. to $1\frac{1}{2}$ in. in 6 ft. for coarse sand, $1\frac{1}{2}$ in. to $\frac{3}{4}$ in. for medium-sized, $\frac{1}{4}$ in. to $\frac{1}{2}$ in. for fine, and $\frac{1}{4}$ in. for slime waters, and may with advantage be greater.

CHAPTER XIV.

JIGGERS AND JIGGING.

Hand Jigging—Primitive Jigger—Automatic Jigging—Hartz Jigger Stroke—Speed and Bedding—Eccentric Motion—Percussive Lever Motion—Elliptical Gearing—Bilharz Circular and Percussion Jigs.

Jiggers and Jigging.—The ore, after having been properly sized in the trommels, is fed direct into machines called jiggers, which effect the separation of the substances—ore and gangue—which have different densities in water. These machines take advantage of the law that, if two bodies of equal volume and of different specific gravities are dropped at the same instant from the same height into a volume of water, the one of the greater weight will sink faster than the other, leaving it behind, and arriving first at the bottom. In ordinary continuous jigging machines the column of water is too shallow to allow of any appreciable separation of one grain from another by simply dropping the grains in together, and so

Fig. 196.—Hand Jigging.

the desired result is accomplished by subjecting such grains to a series of rising and falling—or pulsating—movements. The limits of size between which a mineral can be profitably jigged are from $1\frac{5}{8}$ in. downwards to $\frac{1}{32}$ in. If the ore is coarser than this it requires too much power, and if finer the action of its specific gravity is lessened by friction, and the material lies too close together, so that other means must be adopted for its separation.

The earliest attempts to utilise the difference in the specific gravities of the ore and its gangue was by hand jigging, as shown in the sketch (fig. 196). It is said to have been practised in Bohemia as early as 1519. The sieve is an ordinary one, having a perforated metal or wire netting

bottom; the mixed minerals were thrown into this, and were shaken and jerked up and down in a tub or pool of water, until the lead took the lowest, the blende the middle, and the sand and gravel the uppermost places. These were then removed in layers by means of a scraper.

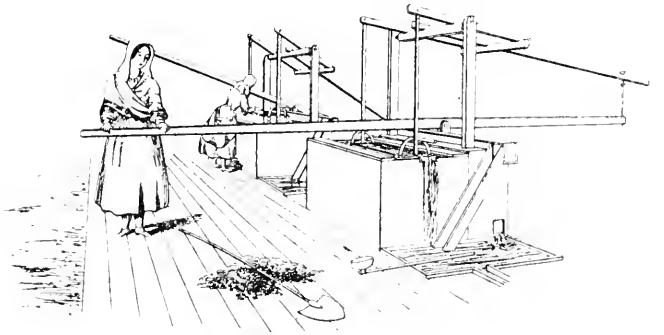


Fig. 197.—Primitive Jigging Machine.

After this the sieve was attached to a frame, as shown in fig. 197, and moved up and down in a cistern or hutch by means of a system of levers. The machine, which is still in use in some parts, is worked by a woman

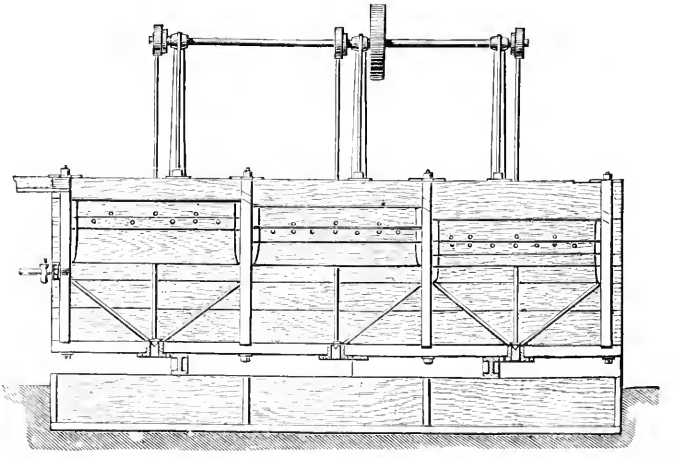


Fig. 198.—Elevation of Jigger.

or boy. The relation of the stroke of the lever to that of the sieve is as 4 ft. is to 8 in.

The connecting rod between the two levers either works in a slot or is loosely bolted, so as to give a jerk to the second lever.

The sieve is filled with a shovel, and emptied by scraping the contents

with an iron scraper. Three classes are usually made—first, the upper layer, which is sterile gangue; then the middle, which consists of mixed lead ore or blende; and lastly, the lowest layer of rich galena, which is clean and fit for sale. The fine sands which pass through the sieve are afterwards treated on a buddle.

Hand jiggers of this type are still in use in Cornwall. The modern improvement of this primitive form of jigger is the automatic machine shown in fig. 198, which is an elevation of a three-compartment jigger, shown also in section in fig. 199.

In this machine the sieves are fixed, and the requisite motion is given to the water by means of a piston working in a separate compartment by means of an eccentric.

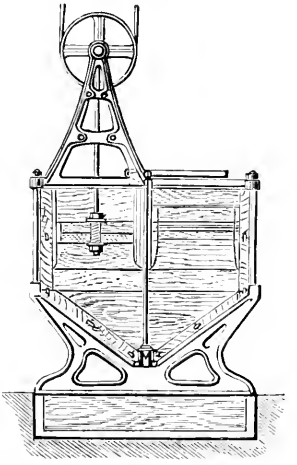


Fig. 199.—Section of Jigger.

The jigger comprises a horizontal hutch, constructed of wood or iron, which is divided into two, three, four, or five compartments, as may be required by the ore to be treated, by transverse ends or partitions. A vertical partition extends down the centre from end to end, along the upper half of the compartments, and on one side of this there are a set of plungers or pistons, worked by the piston rods and eccentrics shown in the illustrations. On the other side horizontal screens or sieves are fixed, on which the sized ore is fed; the screen in one compartment being slightly lower than in the preceding one. The reciprocating action of the piston or plungers causes a regular pulsation of the water, through the screens and the ore bedded upon them causing the mineral to classify itself according to its specific gravity. The heavy ore passes through the holes in the sieve, which are slightly larger than the holes in the trommel which sized the mineral, and is collected in the hutch of the jigger below, from whence, at intervals, it is emptied through a hole closed with a plug valve into the cases below.

The form of the bottom of a jigger is sometimes angular or round, as shown in fig. 199, and sometimes square, as shown in fig. 201, which shows the construction of a three-compartment Hartz jigger.

A description of the Hartz jigger (figs. 200 and 201) will apply generally to every type of this machine. The wooden hutch (p—p^3) is divided into three equal parts by the divisions p^1 and p^2, which form the three compartments of the jigger. Each compartment is again divided for half its length by the partition (f) on one side of which works the piston (e) and on the other side is the sieve (g). The lower part of

each compartment (*i*) is brought down to a point at which is an opening for the outlet of the concentrated mineral. The driving shaft (*a*) is supported on metallic standards, and is provided with a fast and loose driving pulley, whose diameter is varied according to the speed desired.

On this shaft are fixed three eccentrics (*b*, *b*, *b*) which work the three piston rods (*d*, *d*, *d*) attached to the three pistons (*e*, *e*, *e*). Fresh water is supplied from the trough (*h*) to each compartment. The mineral enters at *l*, passes across the beds of the jiggers (*k*, *k*, *k*) which rest on the

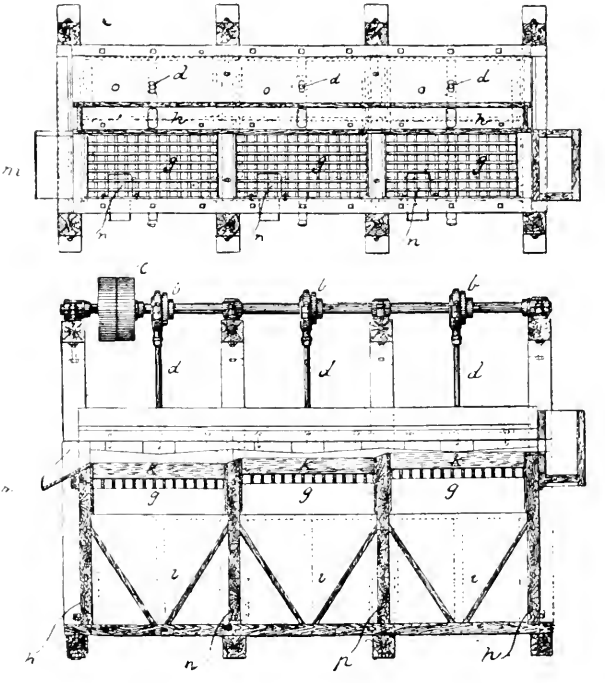


FIG. 200.—PLAN AND LONGITUDINAL SECTION OF A HARTZ JIGGER.

sieves (*g*, *g*, *g*) is deprived in its passage of the rich ore it contains, and leaves the machine at *n*. The stroke of each eccentric can be varied.

In the case of coarse jiggers the holes in the sieves are less than the holes in the trommel which sent down the mineral, and consequently the rich ore piles up on the beds, and would become too thick but that, when it arrives at a certain height, it is allowed to overflow through the arrangement (*n*) into cases put to receive it. The reverse is the case with the fine jiggers. Here the holes in the sieves are slightly larger than those of the trommels, and consequently the rich concentrates pass through, and are collected in the cases (*i*) which are emptied from time

to time by the removal of a plug in the bottom. The compartment in which the pistons work is covered with a board (*o*) to prevent the violent splashing of the water, and is lined with thin boards, which take up the wear, and save the permanent sides of the machine. In the ordinary Hartz jigger the hutch or jigger box is 3 ft. 6 in. deep, and the size of the sieves 2 ft. 4 in. × 1 ft. 6 in.

The Working of Jiggers.—The object in dividing the jigger into a number of compartments is in order to obtain two or more products, as, for instance, when the ore contains both galena and blende the same jigger will effect their separation from each other, and the sterile gangue giving also a mixed product containing both the minerals, which must be sent back to be recrushed. The stroke of the piston of each compartment is regulated according to the work to be done; and for the same reason the composition of the "bed" of the jigger varies on each of the sieves. The speed also of each machine is varied according to the size of the material, the rule being the coarser the mineral the slower the speed, so that the speed will vary from 60 strokes per minute for 10 mm. stuff up to 300 strokes for the jiggers treating the fine sands from the classifiers. The speed at which the jigger is to run is decided upon when the mill is designed, but the stroke is adjusted by the foreman dresser or manager, according to the mineral under treatment, and the amount of enrichment which it is desired to give to the ore. As a general rule, the length of the stroke must be sufficient to lift the ore through a height equal to the diameter of the grains, and the time between the strokes must be sufficient to allow the grains to settle. The end sought after is a stroke which will be just sufficient to lift up and open the bed of the jigger, and allow the rich grains of mineral to pass through; while, at the same time, it drives off the lighter and poorer mineral into the next compartment.

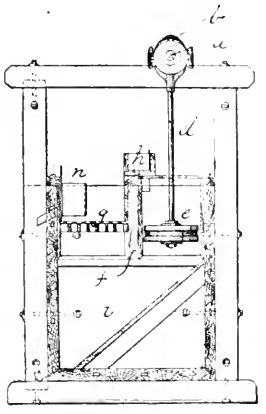


FIG. 201.—CROSS SECTION OF A HARTZ JIGGER.

If the stroke is too great it drives the rich ore over, and the steriles contain too high a percentage of metal; on the other hand, if it is not enough, the poor stuff falls through with the rich, and the percentage of metal in the concentrates goes down.

The following table will give an approximate idea of the length of stroke and speed appropriate to jiggers treating ore from 10 mm. down to $\frac{1}{3}$ mm. diameter. These figures, however, give only general dimensions, for practice with the kind of ore under treatment is the only

way to obtain the best stroke for that ore; and once this is hit upon the jigger will run without further attention to this point.

Size of ore in millimetres	10–$7\frac{1}{2}$	$7\frac{1}{2}$–5	5–$3\frac{1}{2}$	$3\frac{1}{2}$–2	2–$1\frac{1}{4}$	$1\frac{1}{4}$–$\frac{3}{4}$	$\frac{3}{4}$–$\frac{1}{2}$	$\frac{1}{2}$–$\frac{1}{3}$
Approximate length of stroke in inches	$2\frac{1}{2}$	$2\frac{1}{4}$	2	$1\frac{1}{2}$	$1\frac{1}{4}$	1	$\frac{1}{2}$	$\frac{1}{4}$
Number of strokes of piston per minute	60–100					110	120	150–300

The efficiency of the work done by a jigger also largely depends upon the state of the "beds" and the mineral of which they are composed. The bed of a jigger is the layer of ore lying upon the sieve which opens out at the down-stroke of the piston so as to allow mineral of its own specific gravity to pass through. The richness of the concentrates, therefore, will resemble that of the ore of the bed, which, in the first compartment, in the case of a lead mill, would be made of pure galena, accurately graduated as to size, being just a size too big to pass through the holes in the sieve. The products of the first case of one jigger will usually suit for the bed of the machine next smaller in the size of its sieve.

Too much care cannot be taken in order to keep the beds evenly sized and free from impurities, in the shape of large lumps of ore or stray pieces of iron, such as nuts or keys. The thickness of the bed is usually about 2 in. A thin bed means poor concentrates; a thick one makes them too rich and sends on a too great quantity of ore to the next compartment. The happy medium must be found by experiment. Attempts have been made with more or less success to use beds composed of metallic grains, such as lead or iron shots, or of an alloy whose specific gravity would be the same as that of the concentrates desired.

Iron punchings and iron shot, when used for this purpose, are liable to the inconvenience of rusting into a solid mass during any stoppage. An alloy which has been used with success is made of a mixture of iron and aluminium in such a proportion as to bring down the specific gravity of the iron to that of the concentrates desired. It will be found, however, that beds composed of well-sized mineral from the ore to be treated are the best to use and easiest to manage, though, of course, these, as all others, require frequent cleansing and renewal. The sieves are also apt to become clogged with grains of ore and must be cleared, or otherwise; if they become much stopped, the force of the water is sufficient to tear them away from their supports. Ordinary lead shots are very useful as beds for the fine jiggers treating sands.

The man in charge of a jigger should be taught to look after it, keep it in order, clean the beds and change the sieves when necessary. Unless this is done regularly there is a great tendency to leave the work of cleaning and repairing until Sunday for the sake of an extra day's pay.

The steriles from each jigger will require careful attention, especially in

a newly started mill, until the foreman is able to judge by the eye the quality both of the concentrates and steriles. For this purpose frequent assays must be made of each of the products of the machine, and especially of the steriles, by which I mean the waste mineral rejected by the jigger, before allowing them to be thrown to the waste heap. When the tailings or mixed mineral from the fourth and fifth cases contain a recoverable quantity of mineral, they should be sent to the fine crushing mill in order that the minute grains of ore may be separated from the gangue which holds them. The mineral rejected as tailings from the coarse jiggers will, as a rule, always pay for recrushing, but the sands from the fine machines should be valueless.

The output of a jigger will vary between 5 and 10 cubic ft. per hour; the quantity of water used will be from 6 to 12 gallons per minute, and each jigger will require about $\frac{1}{2}$ horse-power to drive. The taps supplying the fresh water must be watched, as the man in charge is usually much addicted to using an excess of water, and as the waste water from the jiggers passes on to the slime machinery, it dilutes the slimes and so makes them more difficult to deal with.

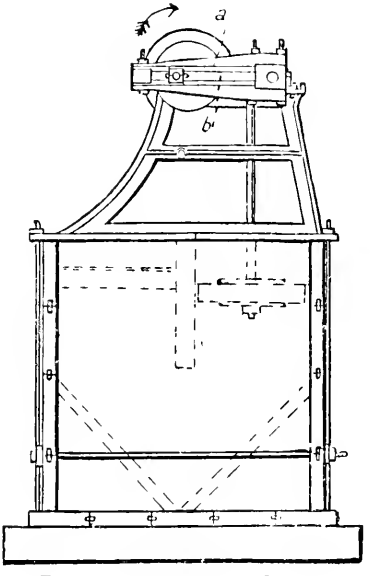


FIG. 202.—LEVER MOTION JIGGER.

The eccentric motion so often employed for moving the piston rods is, perhaps, not the best suited for this purpose, as it gives a smooth, even up-and-down-stroke, whereas what is required is a swift down-stroke, to open up the beds, and a slow up-stroke, in order to give the ore time to settle, and classify itself. Numerous plans have been devised for this, one of which is shown in fig. 202. In this case the driving shaft is separate from the piston shaft, which is driven by means of a crank pin on the disc of the driving shaft and the lever (*a*). As the disc revolves the crank pin slides in the slot (*b*) and is nearer to the piston shaft during the down-stroke, and further from it during the up, thus producing a difference in the speed of the two strokes. An almost similar arrangement is adopted in the fine slime jigger (fig. 203); in this case, however, the crank pin does not slide in a slot of the lever, but works the latter through the intermediary of a connecting rod. In both cases the result is similar, and the length of the stroke can be varied by altering the distance of the crank pin from the centre of the disc.

Another scheme for the same purpose is the use of elliptical gearing, as in fig. 204, by means of which the motion begins at a slow speed, increases rapidly and uniformly until the lowest point is reached, then gradually diminishes until the piston reaches its highest point, the result being a quick and perfect separation of the mineral, as compared with the old eccentrics. The use of gearing of this class is objectionable, however, for other reasons, and is not to be preferred to the lever motion.

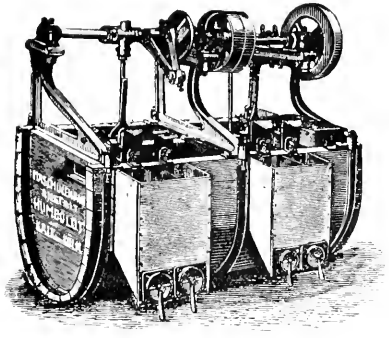


FIG. 203.—SIDE DELIVERY JIGGER, WITH LEVER MOTION.

Fine Jigging.—*Bilharz Percussion Jiggers and Circular Percussion Jiggers.*—In the old days of hand jiggers, illustrated in fig. 197, it was the sieve of the jig which moved, in imitation of the hand-sieve motion, which was the origin of all jigging machines. Afterwards, when treating coarse ore with heavy beds, it was found inconvenient to move the whole mass of material, and so a plunger or piston, setting in motion the water acting against a fixed sieve, was adopted, as in the automatic jiggers shown in figs. 198 and 199. It has, however, been found when treating the sands delivered from an hydraulic classifier or spitzlutten that the old-fashioned method of moving the sieve rapidly is preferable to moving the water, and the Bilharz percussion jig is the result of that discovery.

As will be seen in fig. 205, each jigger consists of one sieve hung by two arms, receiving a vertical motion from an eccentric on the driving shaft, and working in a sieve box which may be adjusted to any height in the framework, so as to allow of the box in one machine being lower than that of another when, as in the illustration, they are arranged in series.

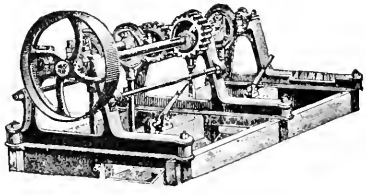


FIG. 204.—ELLIPTIC GEARING FOR JIGGERS.

The sieve is made of perforated copper plate or brass wire, and on it lies the bed most adapted to the size of material to be jigged. The sieves are wider at the supply end than at the discharge, as is also the outer box or casing of the machine.

Each sieve box can, if desired, be divided into two parts by means of a movable division piece, which admits of two products being made at the same time. For this purpose also the box below

is fitted with two discharge openings, one of which, if necessary, remains closed.

The average stroke is about 5 mm., say $\frac{1}{5}$ in., and the speed 220 strokes per minute. The clean water supply is delivered under the sieves and is controlled by a tap.

These jiggers are designed to treat the mineral supplied by the first compartment of an hydraulic classifier or spitzlutten, the stuff from the second being sent to a circular percussion (fig. 205), and that of the third to the Lührig Vanner, as described on page 346 and fig. 234.

Bilharz Circular Percussion Jigger.—In the description of the lead concentrating mill at the Neuhof mine in Silesia, given on page 446, it will be noticed that the sands from the classifier (1.), Plates XII. and XIII.,

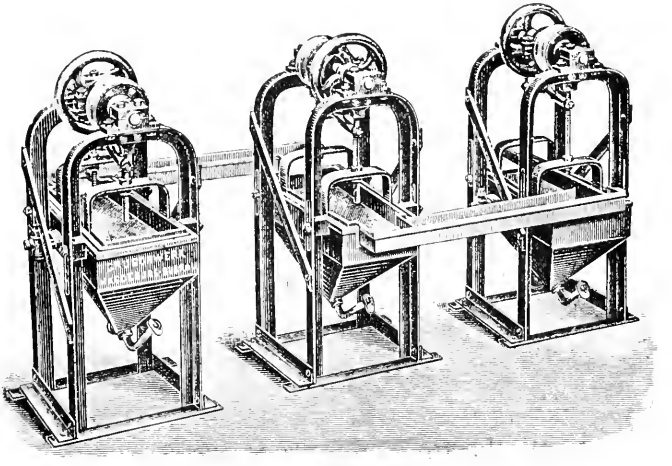


FIG. 205.—BILHARZ SLIME JIGGERS.

are treated partly in fine slime, or Hartz jiggers (R′, R″, and R‴) and partly in circular Bilharz jiggers (s′, s″). The following is a description of these circular jiggers :

The machine (fig. 206) consists of a circular sieve, which is moved vertically by means of an eccentric at the rate of from 200 to 220 strokes per minute, the length of the stroke being from 5 to 6 mm., in a circular outer box, round at the top and cone-shaped below. The sieve is divided into a number of compartments, usually six, according to the requirements, and each compartment carries a bed the size and height of which are regulated according to the size of the material to be treated.

The mineral is fed on to the machine radially ; the rich ore passes through the sieve as in ordinary jiggers, and is discharged through a pipe at the bottom in a thick state of consistency, while the tailings pass away

through a pipe in the centre of the machine. The weight of the sieve and its contents is counterbalanced.

This jigger does not make any middle products; the single product is the enriched and concentrated part of the classified material from the hydraulic classifier. The machine can, however, separately and simultaneously concentrate the sized products of the classifier by leading each separate size to a different compartment of the sieve. Its weight is about

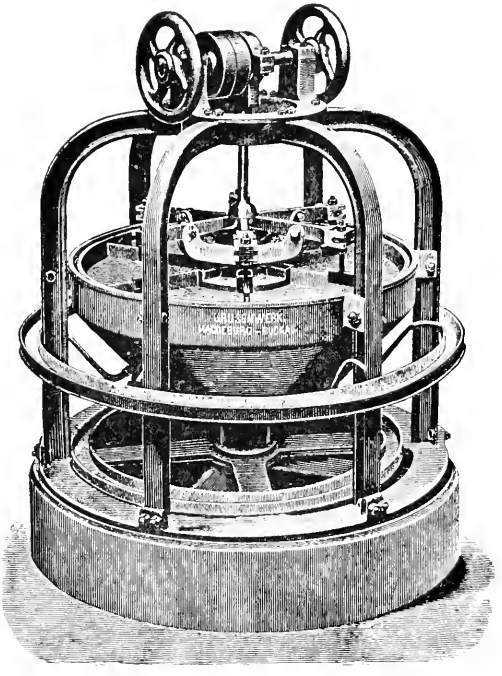


Fig. 205.—Bilharz Circular Jigger.

$2\frac{1}{2}$ tons and price £172. I have had no personal experience of this class of jigger, and in my own practice have used either a Wilfley or a Buss table for the coarser slimes and Lührig vanners for the finer. These will be found described on pages 346 and 357.

We have now passed through the processes of crushing and pulverising the ores, and concentrating them as far as can be done by the methods of coarse concentration which may be said to terminate with fine jigging. The methods adopted for the fine concentration of the pulp or slimes from all classes of mills next demand our attention, and will be discussed in the succeeding chapter.

CHAPTER XV.

MACHINERY FOR FINE CONCENTRATION.

The Mixer—The Round Buddle—The Concave Buddle—The Revolving Knife Buddle—Wooden Percussion Table—Single Percussion Table, End Shake—Gilt-edge Concentrator—Rittinger Table, Side Shake—Hendy's Concentrator.

THE coarse concentration of minerals may be said to end with the process of jigging, although that of fine jigging almost forms an intermediate stage between it and fine concentration proper.

This chapter will therefore be devoted to the description of the various appliances used, either supplementary to jigging or in those cases where, as in gold, silver, and tin milling, the ore has been reduced direct to the state of pulp or slime, and proceeds direct from the stamps or other pulverisers, to the fine concentration machinery.

As a rule the milling process is a continuous one, and the water carrying the finely divided mineral is not allowed to rest and deposit its burden until it has been deprived of its valuable contents. Sometimes, however, this is not the case, as in the retreatment of slimes from the slime pits, and, accordingly, the fine mineral must be thinned with water before it can be concentrated. For this purpose a mixing machine is employed.

The Mixer.—The slimes, when deposited in the labyrinths or settling pits, become hard, and must be broken up and mixed with a certain quantity of water before they can again be treated in any of the machines for concentration. To effect this purpose a mixing machine such as that shown in fig. 207 is generally used, though frequently they are home-made affairs which serve the purpose equally well. The hard slimes are fed by means of a shovel into the hopper, together with a stream of water. Here they come under the action of the revolving blades, which break them up and send them on into the small trommel, through the holes of which they pass and out by the centre spout to the concentration machine. All chips of wood, sawdust, odds and ends of wire, nails, and so forth, are rejected by the trommel, and should be sent to the waste heap, before they can again get into circulation in the mill.

The mixer revolves at a speed of 12 to 15 revolutions per minute, and is usually placed in proximity to the round buddles, percussion tables, or vanners to which the thinned slimes pass direct.

The Round Buddle.—The concentrating machine for slimes, which has hitherto been a great favourite, is the round buddle, shown in fig. 208, and this was perhaps due to the great simplicity of its construction, which permitted its being made out of the odds and ends of machinery usually to be found on a mine. The fixed and revolving

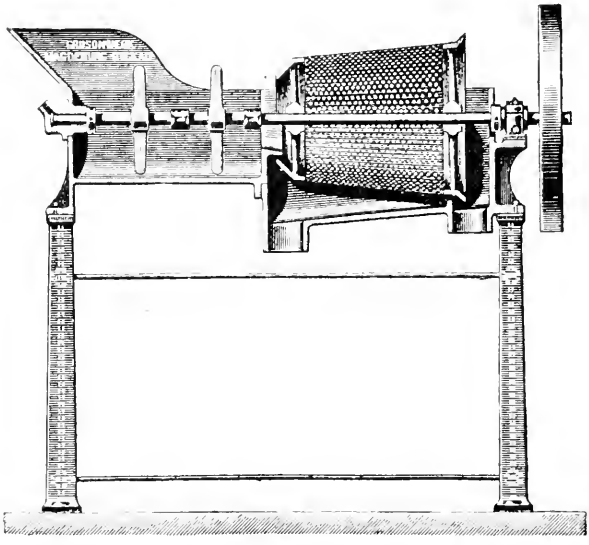


Fig. 207.—The Mixer.

cast iron heads, shafting, bevel wheels, and driving pulleys, can be procured from machinery makers.

The buddle itself consists of a shallow circular pit formed in the ground from 14 ft. to 22 ft. diameter, and from 1 ft. to 1½ ft. deep. The poorer the slimes the greater the diameter, and as the product from the buddle always requires retreatment, it is usual to concentrate first in a machine of small diameter, and then to re-treat the concentrates thus produced in one of a larger diameter. The sides of the buddle pit are formed of stone or brick, set in mortar, and the floor, which has an inclination outwards of 1 in 30, is made either of smooth planed boards or cement run upon a layer of concrete. The centre head is from 4 ft. to 8 ft. in diameter, and may even be less. A revolving head is fixed to the shaft, and this carries four arms. The revolving head receives the slime waters from the trough, and distributes them in an even layer over

the fixed head; the liquid stream, which should be in a uniform thin film, falls over the edge of the fixed head, and distributes itself outwards over the sloping floor of the buddle towards the circumference, depositing in its passage the rich ore it contains, according to its specific gravity, the richest first, close to the fixed head, and the poorest at the circumference. To each of the four arms a board is attached, carrying a cloth or a series of brushes, which sweep round and smooth out each successive layer of mineral as soon as formed. In some cases sprays of fresh water are used instead of the cloths or brushes, the number of revolutions in either case being 3 or 4 per minute, or faster, according to the mineral treated.

The outflow of the waste waters takes place through the small sluice gate shown in the circumference of the buddle. In the door of this sluice is a vertical line of holes, and, as the layer of mineral thickens on

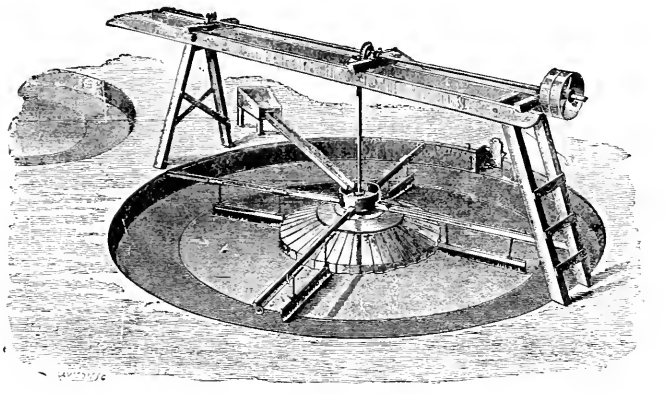


Fig. 208.—The Round Buddle.

the floor, a plug is placed in the lowest hole, and so successively up the series, until the full thickness of the deposit equal to the height of the cone is reached. At this point the machine is stopped, a groove is cut from the cone to the circumference, and samples of the ore are taken and washed on a vanning shovel. By this means an idea is formed as to where the divisions should be made; for at the head the concentrates are rich in galena, and then follow the mixed ores, either of galena, blende, and gangue, if blende is present, or of galena and gangue, if it is absent. Two qualities of the mixed ores are formed. Rings are formed around the deposit on the buddle to indicate the division lines. The rich heads, are taken out and reworked once in another buddle, when they will be rich enough to be sent to the dolly tub (fig. 221–223). The middles are likewise retreated, the ores of approximately the same percentage being treated in the same machine until all the mineral is abstracted, and the waste contains not more than $\frac{1}{2}$ per cent. of lead, and 1 to $1\frac{1}{2}$ per cent.

of zinc. By successive retreatment the minerals may thus be enriched up to 50 to 60 per cent. Pb., and when blende is present, to about 42 per cent. Zn. These concentrates may either be sold as they are, or further enriched in a dolly tub.

The great drawbacks to the round buddle are the facts that no clean products can be made straight away. The mineral must be handled several times, always a costly proceeding, and the machine must be stopped when full, and lie idle until emptied. A large number of buddles

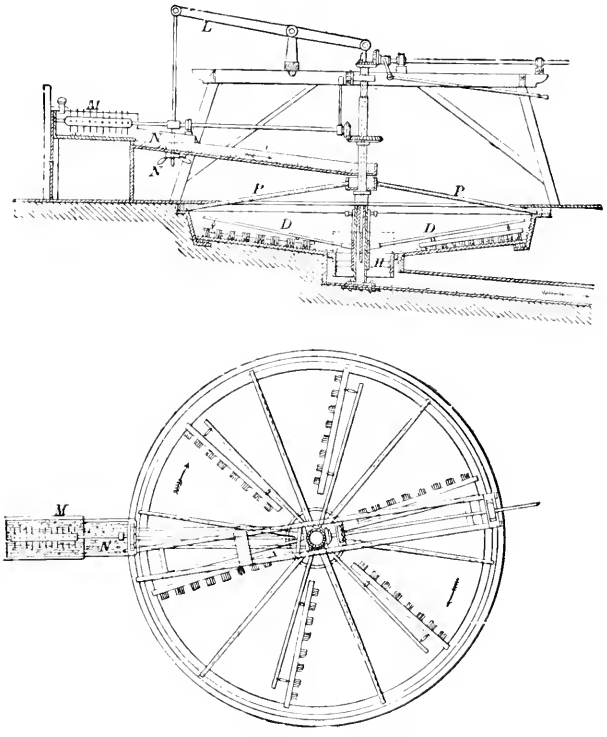


Fig. 209.—The Concave Buddle.

are always required to cope with the slimes from even a small mill; that shown in fig. 308A would require three or four, while in large mills, especially when blende is present, from sixteen to twenty would be needed.

The Concave Buddle.—The buddle which has just been described, might also be appropriately called a convex buddle, seeing that the centre is higher than the circumference, and in contradistinction to this we have Borlase's concave bundle, shown in fig. 209, in which the circumference is higher than the centre where the discharge takes place.

This buddle is suitable for the enriching of the heads of the round buddles, which may be broken up and thinned in the mixer (M), and be deprived of any coarse, foreign matter, by the screen (N). For this purpose the mixer shown in fig. 207 is particularly well adapted.

The ore is fed by means of the trough (N) into the centre of the machine, and is conveyed thence to the circular circumferential edge of the buddle, by means of the six revolving spouts (P) from which it flows uniformly over the conical sloping floor towards the centre (H). The slope of the floor is about 1 in 12. The greatest proportion of the ore is deposited round the circumference of the floor immediately under the circular ledge, while the waste waters flow over the top of the rising ring into the well (H) and away to the settling pits.

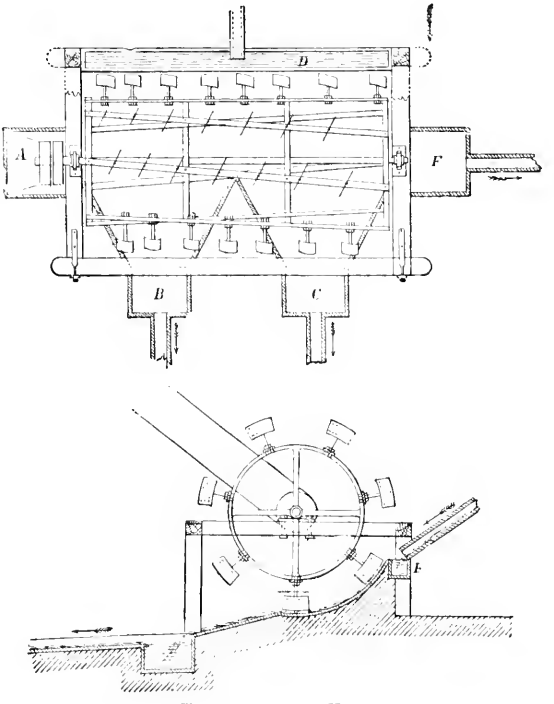


FIG. 210.—THE REVOLVING KNIFE BUDDLE.

Formerly, instead of the rising ring (H) a fixed one, having holes and plugs, was in use, the plug being inserted as the thickness of the concentrates increased. In the more modern machines, however, the ring (H) is made to slide, and its edge may be raised by hand, by means of the rod and lever (L) carrying with it the sweeps (D), which are thus kept at the proper height by the same adjustment. By this means the height of the outflow is adjusted more gradually and uniformly than by means of the plugged holes, while there is less liability of waste from the guttering of the surface of the concentrates.

The Revolving Knife Buddle.—The ordinary flat buddle, which consists simply of a gently sloping floor of boards upon which the ore to be concentrated is shovelled or brushed against a stream of water,

which carries away the lighter particles, and so enriches the mineral, is doubtless the forerunner of the automatic revolving knife buddle, which was brought to its present form by Captain T. Ball, of the Goginan Mines, in Cardiganshire, and has been worked with great success in the Welsh lead mines, especially as a concentrator of heavy ore, associated with a

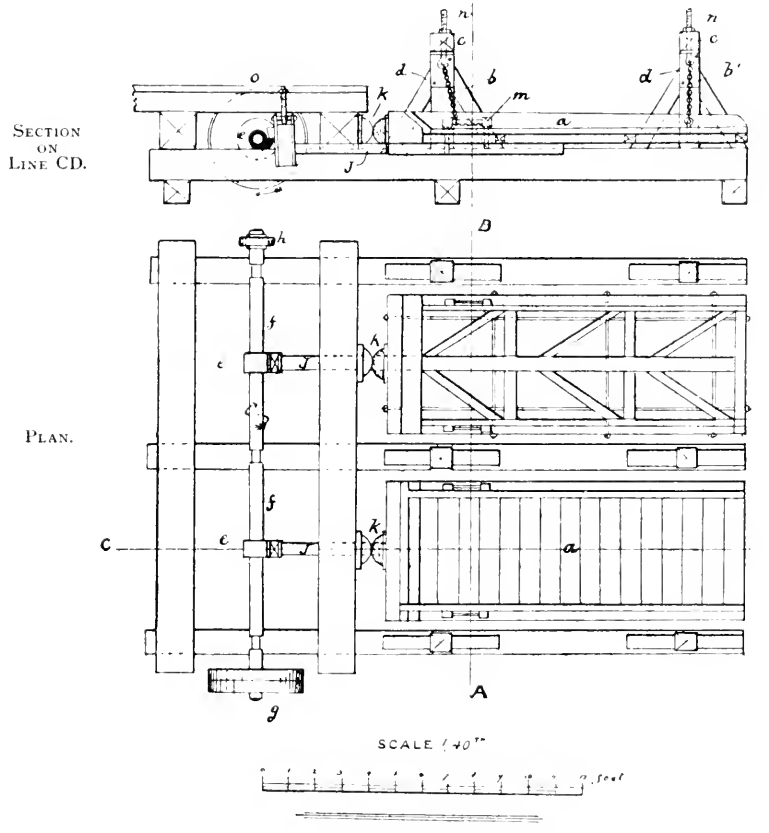


FIG. 211.—DOUBLE PERCUSSION TABLE.

light gangue, such as galena and carbonate of lime, or of coarse-grained oxide of tin, mixed with fine-grained quartz sand.

The machine consists, as will be seen from fig. 210, of a cylindrical frame, $9\frac{1}{2}$ ft. long × 6 ft. diameter over all, rotating on a horizontal axis, and carrying a series of scrapers or knife blades, arranged in spiral lines round its circumference, which revolve close to a cylindrical casing lined with sheet iron, but without touching it. The casing forming the bottom of the buddle, extends rather less than one-quarter round the cir-

cumference of the revolving frame, as shown in the illustration. The ore in the state of slimes is supplied at one end of the buddle from the hopper (A) or from a mixing machine, and is made to traverse gradually along the whole length to the other end (F) by the propelling action of the revolving knives, which are fixed obliquely, and follow one another in spiral lines round the cylindrical frame. A gentle stream of clear water from the launder (D) flows down over the whole curved slope of the bottom of the buddle, and the minerals are gradually propelled to the further end, where they drop, as concentrates, over the edge into the case (F). The machine is driven at the rate of about 20 revolutions per minute, giving the knife-blades a velocity of about 370 ft. per minute. The action of the machine is found to be very perfect, the whole of the stuff being continually turned over by the knife-blades, and pushed against the descending stream of water, which washes out the lighter particles into the cases (B and C). The result is a very complete separation of coarse-grained tin ore in a single operation, with but a small loss in the waste. The contents of the first waste case (B), which contain a small percentage of tin, can be passed through the buddle a second time; but those of the second case (C) are usually too poor for further concentration.

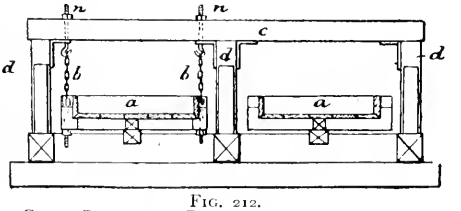


FIG. 212.
CROSS SECTION OF DOUBLE PERCUSSION TABLE.

At the Lisburne mines, in Cardiganshire, the quantity of stuff treated by one of these machines was $2\frac{1}{2}$ tons per hour; the crude ore sent to the buddle contained about 15 per cent. Pb., and the concentrates obtained were of 50 per cent. Pb. By retreating these latter they were further enriched up to 75 per cent. Pb. The crude ore contained quartz blende, carbonate of lime, slate, and lead ore. These machines are useful for enriching the concentrates from fine jiggers or buddles, but not for treating slimes direct.

Wooden Percussion Table.—The situation of some mines, with regard to transport, is often such as to prevent the use of a piece of machinery, owing to its price being enormously increased by the cost of carriage. In these cases the manager endeavours to manufacture, on the spot, some of the minor appliances used in concentration; and it is with this end in view that I give the annexed drawings (figs. 211, 212) of a double percussion table which I have found to work with great satisfaction on ores containing lead and blende, and which would doubtless answer equally well for the concentration of pyrites and other minerals.

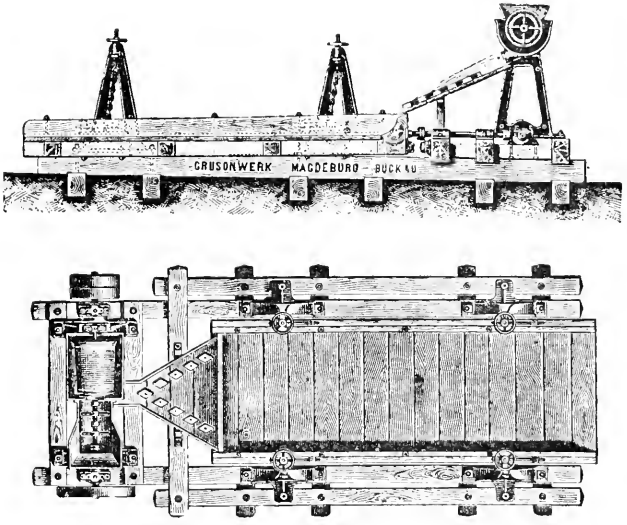
With the exception of the shaft, pulleys, and cams, the whole is made of wood bolted together with such ironwork as the local blacksmith can

make. The machine can be made either with one or two tables, as may be desired.

Each of the tables (*a a*) has an area of 11 ft. 8 in. × 4 ft., and is slung by the adjustable chains (*b b'*) from cross bars supported by means of the stayed uprights (*d d*).

The percussion is given to the table by means of the rods (*j j*) which are forced back about 2 in. by means of the cams (*e e*) fixed on the shaft (*f*) and driven at the rate of about 80 revolutions per minute by the pulley (*g*).

At the end of its stroke the cams (*e*) release the rods (*j j*) and the tables fly back against the buffers (*k k*) one of which is of iron and the



FIGS. 213, 214.—SINGLE PERCUSSION TABLE.

other of wood. The table is slung by the chains (*b b'*), the latter of which hangs perpendicularly when the table is at rest; but in order to give force to the blow, the chains (*b*) can be notched up in the rack (*m*) according to the amount of force required.

The slope of the table can be varied by means of the hanging screws (*n n*). A mixer is fixed on the platform (*a*) driven from the small pulley (*h*) the ore diluted with the necessary quantity of water is fed on to the head of the tables by a shoot which spreads it over the full width of the table.

The drawings are to a scale of $\frac{1}{40}$th, and the under framework of the table is shown in the plan (fig. 211).

The surface of the table should be quite smooth, and the whole of the timber employed should be well seasoned.

The single percussion table shown in figs. 213, 214 is of less primitive construction than the one just mentioned. The table is of wood, and is slung with chains from cast iron supports, the inclination being adjusted by means of the hand wheels. The blow is given by the recoil from the cam on the driving shaft, which also drives the mixer fixed at the head of the table. This mixer is the same as that shown in fig. 207 (p. 302), and the ore to be concentrated, after being fed into the hopper, is broken up and diluted to a proper consistency with water by means of the revolving knives. All coarse foreign matter is rejected by the small trommel, and the slimes are spread evenly over the surface of the table by means of sloping board at the head, on which are fixed diamond-shaped directing pieces. It is of great importance that the slimes should be spread in an even sheet over the full width, as otherwise the water is apt to cut channels through the mineral accumulated on the table and sweep it off, if not carefully watched. The speed should be such as to give about 80 blows per minute, that of the mixer being about 20.

The power absorbed will be from $\frac{1}{2}$ to $\frac{3}{4}$ horse-power for a single table, or 1 horse-power for a double, while the amount of work done

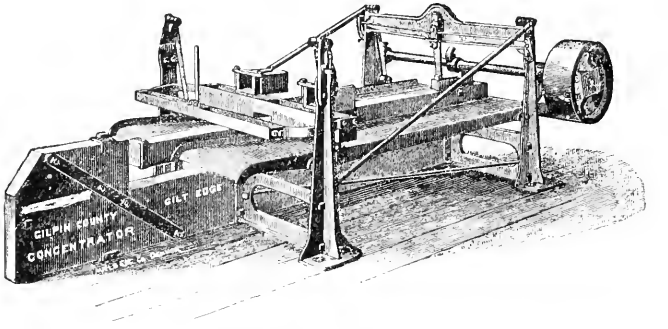


Fig. 215.—Gilt-edge Concentrator.

will altogether depend upon the richness and consistency of the slimes fed into the machine. In order to regularise the speed a heavy flywheel is sometimes fitted to the driving shaft, which improves the working.

Some firms make the whole appliances of cast and wrought iron; but where ease of transport has to be considered it is better, perhaps, to buy only the necessary iron fittings, and make the remainder of the machine of wood from the drawings which will be supplied with them by the makers.

Gilt-edge Concentrator (Percussion Table).—The percussion tables already mentioned are excellent machines and capable of doing good work. Their chief defect is that they are not continuous in their action, and do not deliver the products as they are separated, but,

owing to their construction, must of necessity allow them to accumulate on the surface of the table until the latter becomes as full as it will hold when the machine must be stopped in order to be unloaded of its concentrates. The inventive power of the American machinist overcame this difficulty by removing the board at the top end of the table, and allowing the concentrates to fall over the edge into a collecting case below. This necessitated some structural alterations in the machine, which will be seen in fig. 215. The tables are made of cast iron with a shallow border, and curve up slightly towards the upper end in addition to the usual inclination allowed; and then the plate turns downwards on a sharp curve, over which the concentrates (which, by the action of the repeated blows, have travelled upwards) fall into suitable receiving cases.

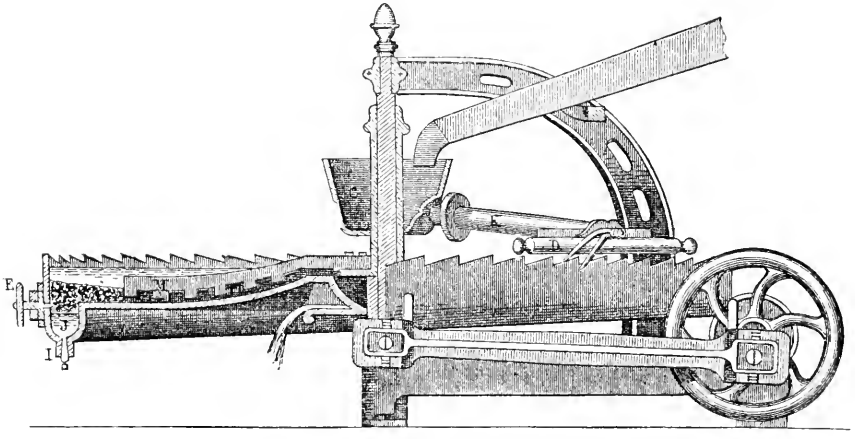


Fig. 216.—Hendy's Concentrator.

The steriles are washed to the lower end, and are carried away by the stream of water to the outside of the mill.

This machine, which I have seen and examined at work in Colorado, is well adapted for treating auriferous pyrites, or any ore containing only one mineral and the gangue, because, owing to its construction, it will only separate into two classes—rich and sterile. In this respect it is inferior to the old form, which will separate two minerals from the gangue, as, for instance, galena and blende from quartz.

Hendy's Concentrator.—A concentrator which has met with some favour as an enricher of the pulp from a stamp battery in a gold mill is that known as Hendy's. The pulp, after having passed over the amalgamated copper plates, and been deprived of whatever free gold it contains, is sent on direct without classification to a Hendy, which concentrates the auriferous pyrites, and prepares them for the subsequent

roasting and chlorination. It would also treat other metalliferous ores in the same manner; but if clean concentrates are desired those obtained from four machines should be sent on to a fifth, where the process of concentration will be completed.*

The machine is shown in fig. 216, and consists of a shallow pan, 5 to 6 ft. in diameter, supported by a vertical shaft in the centre, the pan being made to oscillate by means of cranks on one side, joined to the periphery of the pan, which turns on its vertical axis for a short distance at every revolution of the crank shaft. A frame supports the central pin and crank shaft as well as the arched arm which supports the upper end of the vertical axis. The bottom of the pan, which is shown partly in section in the illustration, is raised slightly in the centre to nearly the height of the arm, in order to facilitate the movement of the particles towards the circumference.

The machine must be carefully levelled; the tailings direct from the plates or blankets are delivered by a trough into the central hopper, from which they pass through the pipe (*k*) and distributer (*d*) into the pan near its outer edge. The distributer (*d*) is caused to revolve by means of two pawls acting on the edge of the pan, and so the slimes are evenly distributed over the whole surface of machine. The distributer (*d*) also carries rake-shaped arms, which continually stir up the concentrates as they settle to the bottom. The crank makes 210 revolutions per minute; and the accumulated pyrites are discharged through the opening (*e*), while any amalgam or mercury collects in the hollow (*j*). One machine will concentrate 5 tons of tailings in 24 hours.

* "The Metallurgy of Gold," by M. Eissler. London: Crosby Lockwood & Son.

CHAPTER XVI.

FINE CONCENTRATION MACHINERY (*continued*).

Evans's Slime Table—The Linkenbach Table—Brunton's Cloth.

Evans's Slime Table.—The inconveniences attendant upon the old form of round buddle, as already described, induced men of an inventive turn of mind to experiment with a view to perfecting the machine, and one of the forms which has met with success is the Evans slime table shown in fig. 217, and also a buddle known as J. Collom's, which is a variation of Evans's table. The slimes from the mixer or classifier are brought to the distributer (B) by means of the launder (A). The distributer is divided into two parts by means of the partition (*a*) in order to separate the clear water supplied by the pipe (*d*) from the slime water. The clear water runs over half the table, while the slime water flows over the other half, the two being kept from mixing by means of the division plate (L). The slime water on one side of the distributer (B) runs through its perforated bottom, and is distributed evenly over one-half of the stationary head (C) and runs on to the rotating table (D), the waste water and steriles falling over the edge into the circular launder (N) and through the waste pipes (O O) to the settling pits; the rich mineral, however, clings to the upper part of the table (D) and is shielded from the action of the clear water by means of the cone-shaped head (C), while the mixed grades are washed about halfway down the rotating table (D), and as the table rotates come under the action of the spray (E) which washes them off into their case (J) through the circular launder (N) and the pipe (K). Lastly, the rich concentrates are played upon by the strong jet (F) and washed off into the case (H) through the pipe (I). The conducting board (G) also helps to prevent any of the rich ore being carried on and mixed with the fresh supply of slimes arising on the table (D).

The second class ore in the case (J) can be rewashed. The head (C) is suspended from the frame (M) so that it can be readily adjusted relatively to the table, as may be required. It will be seen that the action of the table is continuous, and that no mineral is allowed to accumulate upon it. The machine, therefore, can be kept constantly

at work without any loss of time for clearing, as is the case with the ordinary round buddle.

The arms and segments should be made of hard pine, about half-seasoned. The surface of the table should be of soft pine, and must be green and perfectly clear, true, and uniform. The diameter is about 14 ft., and the boards must be tongued and grooved. The speed of the machine is about one revolution in 80 seconds, and the inclination of the table is $1\frac{1}{4}$ in. to a foot, that of the head being $1\frac{1}{4}$ in. to a foot. The capacity is from 25 to 30 tons per day of 24 hours, depending upon the fineness of the material worked, the gravity of the ore, and the degree of concentration effected.

One of the disadvantages of the rotating type of table is that owing to its large diameter a perfectly even motion, which is a desideratum, cannot be obtained; or if the motion is regular it is at the expense of

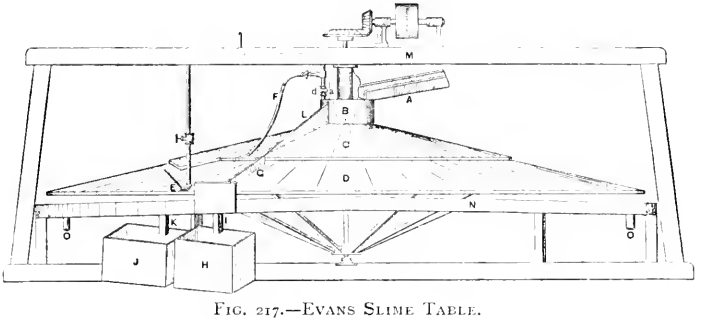


FIG. 217.—EVANS SLIME TABLE.

a loss of diameter, whereas a large diameter is essential to the proper classification and concentration of the minerals. An improvement again upon the Collom buddle is the Linkenbach rotating table, a machine capable of doing excellent work, of which I can speak from personal experience. The rotating Linkenbach, however, was limited as to its diameter by the necessity of an absolutely regular and uniform motion, so that it, in its turn, has been superseded by the fixed Linkenbach table, made of masonry faced with cement. I therefore pass over the rotating Linkenbach, which can be used with great advantage where the space is confined, to the fixed table, which may be made of any reasonable diameter of from 6 to 10 yds., and which, as a concentrating machine for fine slimes, I have found to give perfect satisfaction, though they occupy a large area in the mill which is not always convenient.

The Linkenbach Table.—The treatment of the slimes from a large concentration mill is always one of the most difficult points to be decided, and, as will be seen from the immense number of machines

which have been patented for this purpose, it is one to which serious attention has been paid by many talented men. In the end of the year 1885 I was engaged in studying this matter previous to erecting machinery for the purpose of treating the slimes from a lead mill at a mine in the South of France, and in the course of my investigations visited a large mine near the city of Ems, in Germany, and there saw the Linkenbach tables at work on a large scale; in fact, their inventor was at that time the manager of the mine. After having examined other types of machinery, as employed in various mines in Germany, I decided upon the use of the Linkenbach table for the works over which I was then manager in France, and the results were very satisfactory.

The original Linkenbach table consisted of a cone-shaped table of some 2 or 3 metres diameter, made of iron, and revolving underneath a system of jets. The slime water was fed over the centre of the cone, and as it ran down to the edges deposited the mineral matters according to the specific gravity, and these were afterwards swept off by the sprays of water under which the table revolved. These table are sometimes made of wood faced with cement.

The difficulties with this class of table were to obtain a sufficiently large diameter, and an absolutely smooth motion. In order to get over these the inventor designed a fixed table made of concrete, while the light arms revolved on a framework. A general view of a table is shown in fig. 218, while a plan and section are given in figs. 219 and 220.

The table can be made of any diameter up to 10 or 12 yds., and must be built on well-settled firm ground, so as to avoid any danger of subsequent subsidence, which would alter the slope and crack the smooth cement face of the machine.

Having decided upon a suitable spot, a trench is dug, and the tunnel (O O), of fig. 219, is constructed and arched in brickwork. This tunnel terminates in a well (O), which forms the centre of the table directly under the cast iron buddle head (P), and the utility of this arrangement is that it permits the pipes conveying the slime waters (N), fig. 219, to be fed into the buddle head (P), and also allows access for lubricating to the bearing at the foot of the vertical shaft (P).

The table is first roughly constructed in brickwork or concrete, and over this a smooth layer of hard cement. The slope is usually about 1 in 12. The channels (G), of which there are four surrounding the table concentrically, receive the concentrated mineral which is swept off the surface of the table by means of the sprays (E) into the circular revolving channel (F). The mineral is conveyed from the cement channels (G) by means of small wooden troughs to the various settling tanks (Q^1, Q^2, Q^3, Q^4). The revolving receiving channel (F) is divided by partitions into four parts, from each of which a short spout, seen in the section, conveys the mineral into one or other of the cement channels (G).

A light iron framework (H H) fixed to the shaft (B) which is driven by the worm gearing and shafting (K) supports the iron channel (F) as well as the arms and water sprays (D, E). The supply of clean water arrives by means of a pipe (C) into the centre of the shaft (B), and thence to the sprays (E) as well as to an annular spray, which partly surrounds the buddle head (P) as will be seen by the dots, which are shown on the right-hand half of the buddle head in fig. 220. The function of this spray is to drive the lighter mineral matters down the slope of the table, while that of the others is to wash them off into the channel (F), and so on into the cement channels (G) into the settling tanks (Q). Considerable modifications and improvements have been recently made in this machine, more especially in the driving gear and feed apparatus, with a view to simplification.

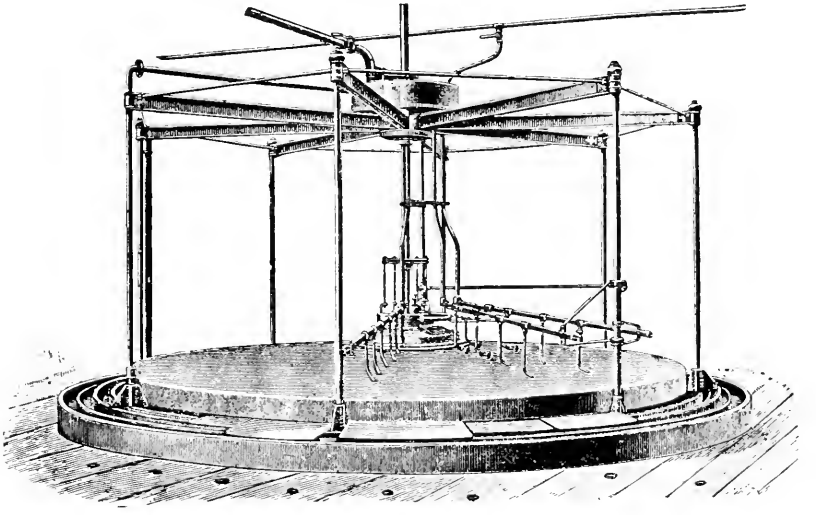


FIG. 218.—THE LINKENBACH TABLE.

The action of the machine is as follows: The slime waters arrive from the spitzkastens or classifiers by means of the pipe (N) and are fed into the buddle head (F) from whence they flow through a horizontal slot over the surface of the table immediately behind the arm with four sprays (E) which, as seen in the section, is advancing towards the reader; the arms as seen in the plan, turn to the left, in the reverse way to the hands of a clock, and at a speed of about one revolution in $2\frac{1}{4}$ minutes. The light sterile slimes immediately rush down the table and over the edge into one compartment of the revolving channel (F), thence by means of a spout into one of the fixed channels (G) and away to the settling tank (Q^4).

The mixed products, however, are deposited on the way; the lighter

ones near the edge of the table, and the richest up near the buddle head. The arms sweep round, and first the mixed product and then the second quality lead, or the zinc, if any is present, are swept off

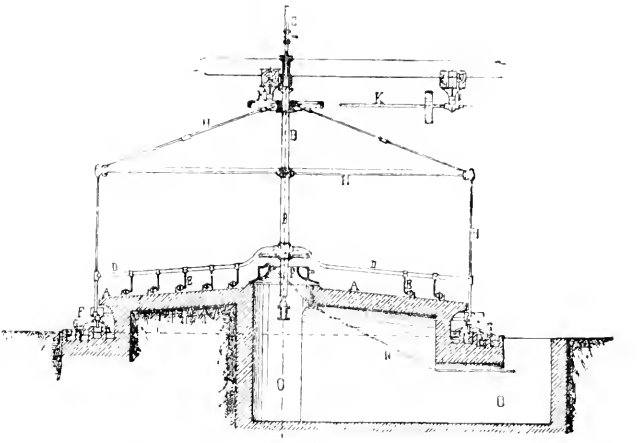


FIG. 219.—SECTION OF THE LINKENBACH TABLE.

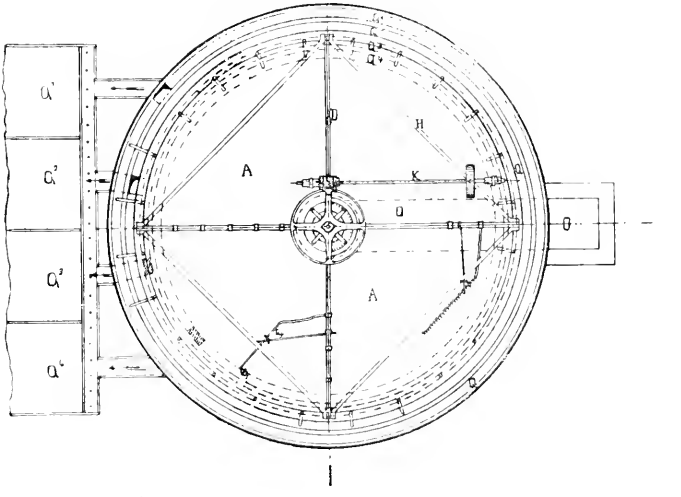


FIG. 220.—PLAN OF THE LINKENBACH TABLE.

by the sprays into their respective channels and tanks; and finally the arm (E) with four strong jets, comes round and clears the table of all that remains, which in the case of galena is an ore containing 50 per cent. Pb., rich enough to be sent direct to market.

The action of the machines is continuous and automatic, and, of

course, it will treat any ores, though I refer to galena and blende owing to my own experience with these minerals. The chief points to be observed are a uniform speed, a constant and regular pressure of fresh water, and a constant supply of slimes. Once these are given and the taps adjusted the machine requires no further attention, but will go on separating the slimes day and night with the regularity of clockwork. The only manual labour required is to empty the settling tanks (Q) as often as they are filled. The steriles will contain about 0·5 per cent. Pb.; the mixed products from Q^3 can be retreated over the table, or, better still, upon a percussion table; while if no zinc blende is present, the two cases (Q^1 and Q^2) can be mixed and sent to the magazine, and will contain about 50 per cent. Pb. If there is much silver in the ore, it is not advisable to concentrate to such a high percentage, owing to the loss of the precious metal which is certain to occur. The exact limit can only be ascertained by assay and experiment.

The price of the framing, tubing, and gearing, with all the taps and connections, shafting, etc., at Cologne, is approximately as follows:

Diameter of Table.	Marks.	£
6 metres	2900	= 145
7 ,, ...	3200	= 160
8 ,, ...	3500	= 175
10 ,, ...	4600	= 230

With regard to the amount of slimes which one of these tables is able to treat, the following information relative to the three machines I saw working at Ems will be of interest: In every 10 hours the table No. I. received from the spitzkasten No. 1 7230 kilos. of solid matter; table No. II. received 5160 kilos. of solid matter from No. 2 spitzkasten; table No. III. received 1050 kilos. of solid matter from No. 3 spitzkasten. The amount of slimes running into the first spitzkasten was 453 litres, containing 23·93 kilos. of solid matter per minute, while the amount overflowing from No. 3 was 228 kilos. per minute, containing 0·62 kilos. of solid matter; so that the total quantity of solid matter treated for 10 hours by the three tables was, in round numbers, 14,000 kilos. (14 tons). In most mills one single table would suffice for treating the whole of the coarse slimes, and so the third table only receives the insufficient quantity of 1650 kilos., whereas it could treat three times as much.

Supposing, however, that there was a sufficient quantity of slime waters to supply three tables, then the maximum amount they would be capable of treating would be as follows: No. I. table, 10,000 kilos.; No. II. table, 7500 kilos.; No. III. table, 5000 kilos—the kilo being equal to $2\frac{1}{4}$ lb. With regard to the coarse sands of the mixed products, it is wiser to treat these apart on a percussion or shaking table, and not to send them back again to the tables. In some cases they can be sufficiently enriched by means of a dolly tub.

Perhaps the only inconvenience to be urged against the use of Linkenbach tables is the space they occupy, and the absolute necessity of having a solid foundation, for the least settlement of the ground would at once throw the whole arrangement out of gear, and probably crack the surface, which should be absolutely smooth, so as to offer no obstacle to the clean sweep of the mineral across it.

The Tossing or Dolly Tub.—One of the best appliances for enriching the second quality slimes from the Linkenbach tables or buddles is the tossing or dolly tub, which, indeed, is of so simple a construction as to be readily made on the mine. In its least complicated form it consists merely of a strong oaken tub about 36 in. deep, 30 in. diameter at the bottom, and 36 in. at the top, as shown in fig. 221.

About 8 in. below the top a strong iron ring is fixed, which receives the blows of the bars (*d*), of which there are two, each worked by a man, who places the point in a hole in the floor and strikes the ring at

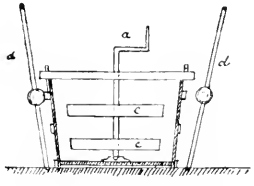


Fig. 221.—The Tossing or Dolly Tub for Hand Power.

Fig. 222.—Section of Contents.

the rate of from 80 to 100 blows per minute. Each bar is bulged out into a ball at the point where it will strike the ring. Inside the tub is a wooden dasher (*c*) turned by the handle (*a*). At the commencement of the operation the tub is filled about one-fifth full of water, and then one man slowly fills in the slimes while two others turn at the handle at the rate of about 40 revolutions per minute. The slimes are thus well mixed up, and when the tub is nearly full the dasher is rapidly removed, and the men commence to tap with the bars; thus hastening, by the vibration, the settlement of the rich heavy slimes. After the tapping has been continued for some time the slimes settle down and are then dug out with a spade. The section (fig. 222) which is from a long series of trials made by myself, will give an idea of the way in which the contents have been enriched. At the bottom is a thin layer of coarse-grained sands, which is not so rich as the superposing one, and that again is hardly so rich as the one above; after which, the quality rapidly falls off, until at the surface there is only a layer of barren sand.

If the slimes have been subject to a perfect classification before tossing, the richest will be found at the bottom; but as a general rule the presence

of some coarse, badly classified slimes will usually prevent this; which, after all, is immaterial, as the bulk of the ore is sufficiently rich to be sent to the magazine. The second quality can be retreated as may be desired.

In its primitive form the tub is not an economical arrangement, as it requires too much labour; and the arrangement shown in fig. 223 designed by myself will be found not only less expensive, but more effectual, as it permits of the tapping being carried on at the same time as the loading and stirring. In my own case I found that the combined tapping and stirring made a difference of 8 per cent. in the quality of the products.

The tub itself is the same as before, but is mounted on wheels running on a short line of rails, the object of which is to allow of the tub being run from under the gearing for the purpose of being emptied.

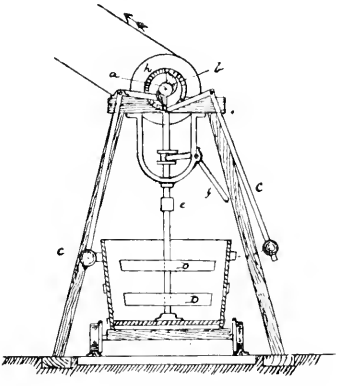


FIG. 223.—DOLLY TUB WORKED BY MACHINE POWER.

On the horizontal shaft (*a*) a double cam (*b*) is fixed which rocks the two levers (*c c*) and so causes the ball-shaped hammers to strike the ring at the rate of some 80 blows each per minute.

The dasher (*d*) revolving at a rate of about 40 per minute by means of the bevel wheels (*h*) is readily removable; all that is required when the loading is finished is to depress the handle (*f*) which raises the clutch (*e*) and allows the dasher to be lifted out. The tapping is continued until the slimes have settled down, and then the machine is stopped and the tub pushed from under the gearing for the purpose of being emptied.

The slimes can be enriched by this means up to any requisite percentage without any loss of silver, as but very little water is used, and that does not flow off continually, but is allowed to settle before being drained away.

Brunton's Cloth.—The Frue and Lührig Vanners about to be described in the next chapter are the latest and most perfect development of a principle which had long been experimented with in Germany and England, that of the Brunton cloth. The original machine, illustrated in figs. 224, 225, consisted of a revolving belt of coarse canvas (*a a*), stiffened with paint, and strengthened and kept level across the face by means of laths of elm, a few inches apart.

The cloth moves over a flat boarded surface (*b*) supported on a frame which is inclined at an angle of about 1 in 6. This inclination can be

adjusted by suspending screws at the bottom of the frame. The cloth passes over the top roller (*d*), and is allowed to dip under the surface of the water in the collecting tank (*f*), then up and over the roller (*d*) and back to the surface of the table by the foot roller (*a*).

The cloth travels upwards at the rate of about 15 ft. per minute. The slime waters arrive at *h*, and are spread evenly over the face of the cloth. A stream of clear water, arriving by a spray at *i*, has sufficient

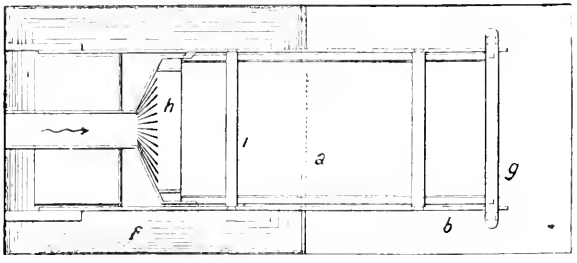


Fig. 224.—Plan of Brunton's Cloth.

force to carry away the light particles; but the greater adhesive power of the grains of ore enable them to withstand it, and they remain attached to the cloth until they are carried over the roller, and under the surface of the water in the tank (*f*) when they fall to the bottom.

There are three adjustments to make for treating different nature of stuff, viz., inclination of the belt, rate of movement, and quantity

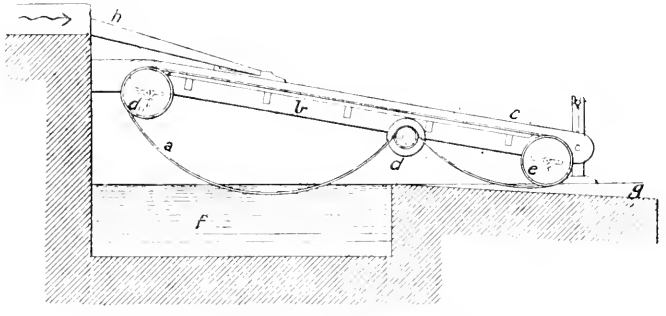


Fig. 225.—Section of Brunton's Cloth.

of clear water admitted. The apparatus, as generally used, is fairly efficient, and its construction is so simple that it can be made on the mine. On the German dressing floors its efficiency is increased by giving it a slight end percussive motion, but although fairly good results are obtained from it there is a very great difficulty in making the belts sufficiently durable.

As to the amount which may be treated on this simple machine, it is not easy to fix the exact quantity, but in Spain it is found that with one such machine a slight return pays the costs; a boy at 10*d.* per day being all the labour required, while, from two such appliances, from 5 to 6 tons of ore per month were obtained, containing 45 per cent. Pb., and at a cost of 10*s.* per ton. Before sale, however, this mineral was further enriched in a dolly, or tossing tub (see fig. 221), up to 70 per cent. Pb.

The following are the general dimensions of this machine, and the approximate amount of work which it will accomplish when treating lead slimes:

The length of the table is 16 ft., and its width 6ft. It is set on an inclination of 9 in. in its length, the rule being that the richer the stuff the greater the inclination. The speed of the cloth is 3 revolutions per minute, and the number of blows 75 per minute, the length of the stroke being $1\frac{1}{4}$ to $1\frac{1}{2}$ in. Under these conditions the cloth will treat about 200 cubic ft. of slimes per 24 hours, containing 4 per cent. of lead. The amount of concentrates obtained is 80 cubic ft., enriched up to 10 per cent. by one passage over the table, and the quantity of water required was 12 gallons per minute. With rich stuff the quantity is less.

The slimes were first put through a mixer, such as that shown in fig. 207, in which they were thinned down with the water before passing on to the cloth. The mixer made 9 revolutions per minute, and the number of holes in the trommel as well as of those in the sieve of the stamps was 72 per square inch.

It will be observed that no attempt was made to classify the slimes before they were fed on to the cloth. This we think is a great error, and this applies also to the usual practice with regard to the Frue vanner. Perfect concentration cannot be obtained without previous classification, and the more perfectly the one is carried out the more satisfactory will be the results obtained from the other.

CHAPTER XVII.

FINE CONCENTRATION MACHINERY (continued).

The Frue Vanner—Description—Method of Working—Rules for Proper Consistency of Pulp—Price, Weight, and Capacity—the Improved Frue Vanner—Directions for Setting-up—Directions for Running.

Frue Vanners.—The Frue vanner, which is the modern development of the Brunton cloth, described at the end of the last chapter, is the outcome of a long series of experiments in the concentration of silver ores, carried out from 1872 to 1874 by the late Mr. W. B. Frue, assisted by Mr. W. McDermott.

Belts with various motions were tried, but in the end the superiority of one with a side shake was decided upon, owing to the close saving effected, although it seems to have been a keen competition between the machines having an end shake, with which the name of Embrey is associated (see fig. 230), and those with a side shake, called after Mr. Frue. The same firm * now manufactures both the machines, and holds the patents. In experiments on the same class of ore, it has been found, when comparing side and end shake machines, that the end shake belt must either be placed at a greater inclination than a side shake or vanner belt, or more water used, or a more rapid shaking motion employed in order to give equally clean concentrations. It is, therefore, possible that under certain conditions in some mills the Embrey may prove more convenient than the Frue vanner.

It will be seen by reference to fig. 226 that the main feature of this machine is an endless inclined rubber belt, supported by rollers so as to form a plane inclined rubber surface, 4 ft. wide, 12 ft. long, and bounded on the sides by rubber flanges. The belt travels up the incline, and round a lower drum, which dips into a water tank where the mineral is collected. In addition to the travel of the belt, the latter receives a steady shaking, or settling motion from a crank shaft along one side, the shake being at right angles to inclination and travel of belt. The ore is fed on in a stream of water, about 3 ft. from head of belt, and flows slowly down the incline, subjected to the steady shaking motion, which

* Messrs. Fraser & Chalmers, Ld., London and Chicago.

deposits the mineral on the belt. At the head of the belt is a row of water jets.

The slow upward travel of belt brings up the deposited mineral, and the water jets wash back the lighter sand, letting only the heavy mineral pass, and deposit in the water tank below. The endless belt has long been known, and has been described on page 319, under the name of the Brunton cloth, but the shaking motion and rubber belt used in the vanner makes an entirely different machine, enabling a separation to be made more perfect than with any other machine, owing to the small inclination of belt necessary (from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. to foot), and very much less water than was ever before possible. The capacity of the machine is from 5 to 10 tons per day of 24 hours, according to ore treated. With very fine ore containing rich mineral, large capacity and close work are utterly incompatible. The quantity of rock treated will depend upon several circumstances. If the ore be of the very finest slimes, of course,

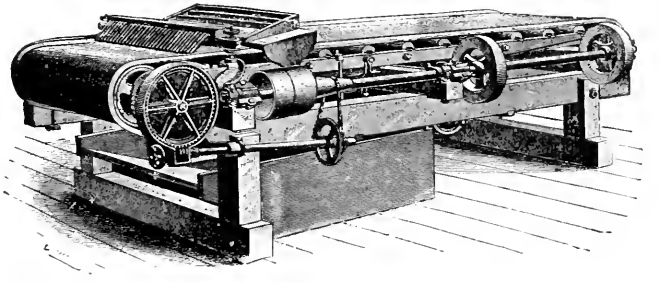


FIG. 226.—THE FRUE VANNER.

not so much can be treated as if some of the material be coarser. If a good separation be required, the machine should not be crowded. When the ore is stamped and screened through a screen, having 50 holes to the linear inch, from 4 to 6 tons can be well separated; if the ore is a little coarser from 6 to 10 tons can be calculated upon. For running a single machine the power necessary is $\frac{1}{4}$ horse-power, while one man can attend to 16 machines without difficulty, as the only work necessary, once they have been adjusted, is to oil them and keep them clean about the working parts, regulate the water and scrape out the concentrated mineral occasionally from the water tank. When six machines are used the cost of treating sand, when it is ready to flow on to the machine, is estimated at less than 10*d*.

When the speed of the machines is continually varying as well as the quantity of ore delivered, the above conditions do not apply, as it is essentially necessary that the speed and feed be absolutely regular and unvarying. To illustrate this very simply, watch a man tending one vanner in a mill where engine speed or water supply is irregular. Every

change of speed of engine or volume of water needs a corresponding change of machine, either in water or belt travel. Next step into a mill, as several may be seen in California, with 16 vanners running like a single

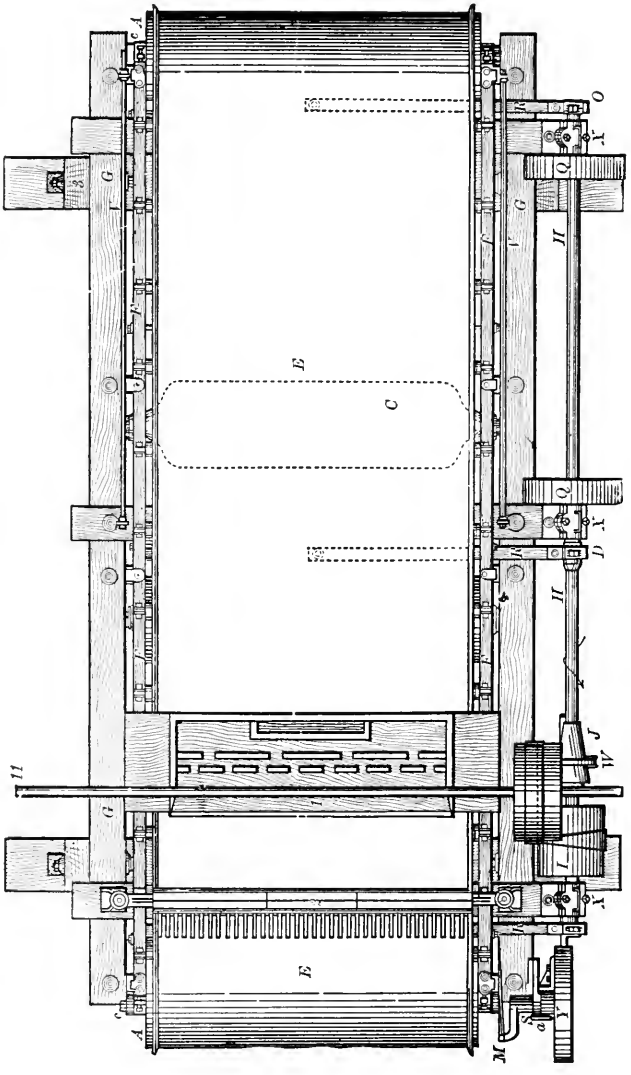


FIG. 227.—PLAN OF THE FRUE VANNER.

piece of clockwork, and one man keeping a general eye over them while handling the concentrations produced. The two cases answer all objections as to complication and difficulty of adjustment: in the first, one man is driven wild watching a single machine; in the second case,

one man has an easy job looking at 16 machines, which are treating 80 to 100 tons of ore every day.

The following description together with the drawings will give an accurate idea of the construction of these machines:

A A are the main rollers that carry the belt and form the ends of the table, Each roller is 50 in. long and 13 in. in diameter; made of sheet iron, galvanised, and is light and strong. The bolts which fasten the boxes of A A to the ends of F, also fasten to F the upper supports which rest on uprights (N, etc.). B and C, are of the same diameter, and are made in the same way as A A. The roller part of C is shorter than that of A A and B, and also has rounded edges, the upper surface of the belt with its flanges passing over it. The belt E passes through water underneath B, depositing its concentrations in the box (No. 4); and then passing out of the water the belt (E) passes over C, the tightener roller. B and C are hung to the shaking frame (F) by hangers (P P) which swing on the bolts fastening them to F. By means of the hand screws B and C can be adjusted on either side, thus tightening and also controlling the belt.

The boxes holding A A in place have slots and adjusting screws, so that by moving them out or in A A can be made to create a very strong influence on the belt (E); and as E sometimes travels too much towards one side, this tendency can be stopped most quickly by lengthening or shortening on one end or the other of A A; remembering that the belt always travels to the loosened side. The swinging of B or C also controls the belt.

c c are bolts and washers to take up end play of rollers (A A); these bolts pass through holes in the gudgeons of A A.

D D, etc., are the small galvanised iron rollers, and their support causes the belt (E), to form the surface of the evenly inclined plane table. This moving and shaking table has a frame (F) of ash, bolted together, and with A and A as its extremities. This frame is braced by five cross pieces. The bolts holding together the frame pass through the sides close to the cross pieces; the cross pieces are parallel with A A and D D, etc., and their position can be understood by the three flat spring connections (R, O, etc.) which are bolted to three of them, one to each, underneath the frame.

The belt (E) is 4 ft. wide, $27\frac{1}{2}$ ft. in entire length; being an endless belt of rubber with raised sides.

G G is the stationary frame. This is bound together by three cross timbers, which are extended on one side to support the crank-shaft (H).

G G supports the whole machine, and the grade or inclination of the table is given by elevating or depressing the lower end of G G. This is accomplished by means of wedges; for this frame rests on uprights

(Nos. 3 3) fastened to two sills, which form the foundation of the machines in the mill.

F is supported on G G by uprights (N, etc.); four on each side. These uprights are of flat wrought iron, with cast iron bearings above and below; each middle bearing on F has one bolt hole, and there are two of them on each side. The end ones have two bolt holes, and there are four of them, two on each side. These bolts pass through the frame (F) and also hold to the frame the bearings of A A, which work in a slot. The bearings of A, the upper or head roller, are higher than those of A, the foot roller, *i.e.*, A is a trifle higher than the regular plane of the table, and the first small roller (D) should be raised a trifle.

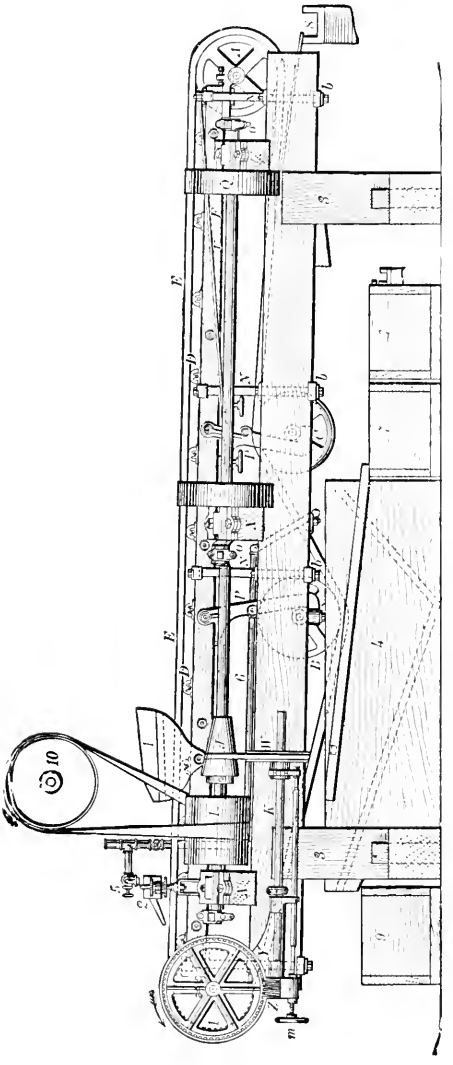


FIG. 228.—LONGITUDINAL SECTION OF FRUE VANNER.

The shape of the lower or bottom bearings of the uprights (N, etc.), can be understood by examining *b*, as shown in the end elevation, and partly in the elevation. This lower bearing (*b*) extends across G, underneath, and is supported by a bolt passing through G. A lug on the upper side and on the outside end of *b* rests on G; and *b* hangs on the head of the bolt, and is kept stationary by the weight of N and its load. By striking with a hammer the face of *b* shown in the elevation, *b* is moved, changing the position of the lower bearing, and thus making N more or less vertical. By thus moving the lower supports of N, etc., the sand corners on the belt hereafter explained are regulated.

The cross timbers binding together G G and resting on them, are

extended on one side, and on these extensions rests with its connections the main or crank shaft (H). This crank shaft has its bearings (X, X, X) on which are brass cups for lubricating compound; the cranks are $\frac{1}{2}$ in. out of centre, thus giving 1 in. throw.

I is the driving pulley that forms with its belt the entire connection with the power.

J is a cone pulley on the crank shaft (H). By shifting the small leather belt connecting J and W, the uphill travel of the main belt (E) is increased or diminished at will. The small belt connects to J the flanged pulley (W) which is on the small shaft (K) and by means of the handwheel can be shifted on K and held in place. The bearings of K are fastened to Y. Y is a cast iron shell protecting the worm (Z) and the worm gear (L); Y turns on a bearing bolted to the outside of G, and thus becomes a fulcrum for W and K. The object gained by this is that the weight of W and K (from Y) hangs on the small leather belt, preventing slipping or wear, at the same time making it positive.

a is a screw used to relieve the small belt from the weight of K and W, taking all the strain off the small belt, and thus stopping the uphill travel instantly when desired.

m is a hand screw by means of which the pulley can be moved, adjusting the small belt on the cone (J) thus regulating the uphill travel.

K is the worm shaft and terminates in a worm (Z) which connects with a worm gear (L). L travels in a bearing bolted to the outside of G. Z and L are protected from dirt by the shell of cast iron (Y) enveloping both.

The short shaft which L revolves, terminates in an arm (S) which drives a flat steel spring (M)—which is a section of a circle—connected with the gudgeon of A.

N, etc., are the upright supports of the shaking table (F) carrying the belt (E).

R, etc., are three flat steel spring connections bolted underneath the cross pieces of F, and attached to the cranks of the shaft (H) by brass boxes (O, etc.), on which are cups for lubricating compound. These springs give the quick lateral motion—about 200 a minute.

Q Q are two flywheels.

V V are two rods passing from the middle cross timber to the lugs for same at the foot of F. The cast iron washers on the bolts of the cross timbers have lugs cast on them. V V pass through these lugs, and at each end are nuts on each side of the lugs. Thus, V V prevent the movable frame (N) from sliding either up or down, and by them F is squared.

No. 2 is the clear water distributer, and is a wooden trough which is supplied with water by a pipe, and the water discharges on the belt in drops by grooves 3 in. apart. Another form generally used for No. 2

is an iron trough with brass spout $1\frac{1}{2}$ in. apart, so that by blocking every other hole, water jets can be made 3 in. apart.

No. 1 is the ore spreader, which moves with F, and delivers the ore and water evenly on the belt.

n is a copper *well* that fits in (and shakes with) the ore spreader at the place shown in the drawing. This is used in concentrating gold ores, for saving *amalgam* and *quicksilver* escaping from the silvered plates above, and can be taken out and emptied at any time. Into this well falls all the pulp from the battery. Its ends are lower than the wooden blocks of the spreader, so that the pulp passes over the ends of the well and is evenly distributed.

For some gold ores it is desirable to use on the ore spreader a silvered copper plate the size of the spreader, and when this is used the wooden blocks of the spreader are fastened to a movable frame on top, so that

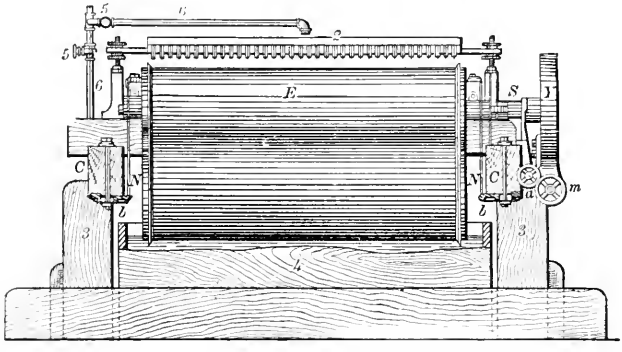


FIG. 229.—END ELEVATION OF FRUE VANNER.

they can be removed when the plate is cleaned up once or twice a month. (This amalgam saver is charged extra for.)

Nos. 5, 5 are the cocks to regulate the water from the pipes (Nos. 6, 6).

Nos. 3, 3 are upright posts, which are firmly fastened into two sills. These posts are cut down on the inside to make square shoulders on which G G rests.

No. 4 is the concentration box, in which the water is kept at the right height to wash the surface of the belt as it passes through.

Nos. 3 and 4 are generally made at the mill; but can be supplied by the makers at a cost of about $18.

The overflow from No. 4 contains finely divided sulphurets in suspension; to settle them the water passes through boxes (Nos. 7, 7, 7).

No. 8 is a section of the launder to carry off the tailings.

No. 9 is a box into which the concentrations fall when scraped out of No. 4.

Nos. 7, 8, and 9 are made at the mill.

Nos. 10 and 11 show arrangement of countershaft with tight and loose pulleys for driving machine, but should be higher above machine than shown in drawing.

Method of working.—The ore is fed with water on the belt (E) by means of the spreader (No. 1). Thus the feed is spread uniformly across the belt. A small amount of clear water is distributed by No. 2, which is a wooden trough in which is a pipe (No. 6) or an iron trough with brass spouts.

Both No. 6 and No. 2 can be supported from the upper cross-timber of G G.

A depth of $\frac{3}{8}$ to $\frac{1}{2}$ in. of sand and water is constantly kept on the table.

The main shaft (H) should be given the proper speed for each kind of ore. We seldom find the ore in one district just the same as in other places, but when the machine is adjusted to the ore, and the best speed is established, this motion should be kept uniform. The best motion will probably be found between 180 and 200 revolutions of the crank-shaft per minute, with 1 in. throw.

The uphill travel or progressive motion varies from 2 ft. to 12 ft. a minute, according to the ore; and the grade or inclination of the table is from 3 in. to 6 in. in 12 ft., varying with the ore. The inclination can be changed at will by wedges at the foot of the machine, these wedges being under the lower end of G G, and resting on shoulders of uprights, form the main timber of the mill.

The motion, the water used, the grade, and the uphill travel should be regulated for every ore individually, but, once established, no further trouble will be experienced in the manipulation.

In treating ore directly from the stamp, too much water may possibly be used by the stamps for proper treatment of the sand by the machine. In such a case there should be a box between the stamps and the concentrator, from which the sand with the proper amount of water can be drawn from the bottom; and the superfluous water will pass away from the top of the box; but as mineral will also pass away with this water, there should be settling tanks for it, and the settlings can be worked from time to time as they accumulate.

The main body of the belt suffers hardly any wear at all, since it merely moves its own weight slowly around the freely revolving rollers; and the life of the belt is lengthened by this *precaution*; viz., to keep it clean from sand at every point except the working surface; thus sand cannot come between the belt and the various rollers. All the bearings should also be kept clean; a machine cleanly worked gives better results, and less wear and tear, and requires less power to drive than a machine allowed to be covered with dirt. With a clean machine the wear of bearings is very slight.

The concentration box (No. 4) which is kept full of water, and through which E passes, may be of any size or depth desired. Though not indispensable, it is best to have a few jets of water playing above and underneath on the belt as it emerges from the water in No. 4, so as to wash back any fine material adhering to the belt, and as such a method will cause an overflow in No. 4, the waste water, being full of finely divided mineral, should be settled carefully in the boxes (Nos. 7, 7, 7). Every few hours the concentrations may be scraped out with a hoe into the box (No. 9) and if this box be on wheels, it can be readily run on a track to the place where the concentrations are stored.

Rules for Proper Consistency of Pulp.—That the proper quantity of water with the pulp from the stamps is used is very important, and this should be carefully regulated. There should be formed on each side of the belt a *slight corner* of *sand*, *i.e.*, there should be on each side sand, with less water in it than there is in the balance of the pulp on the belt. If there is not a slight sand corner, the corner will be sloppy, and there will be a *loss*. *Sloppy corners* are caused by using *too much* water with the pulp from the stamps passing on No. 1.

Frequently, on the other hand, there may not be *enough* water with the pulp from the stamps, and the result will be *too heavy* sand corners. The remedy for this is to use *more* water in the pulp coming on No. 1.

As regards the proper amount of water to be used in the water spreader (No. 2) use just enough (no more) to keep covered the *field* between No. 1 and No. 2, so that no points (or fingers) of sand shall show on the surface. The whole width of the belt between the water spreader and ore spreader should be kept quite wet. If dry streaks or points occur, and water, as a consequence, runs in streaks, at the junction of the wet and dry channels mineral will be picked up and "floated" away on the surface of the water; this "floating" of mineral is caused by its dryness, not by its lightness: it has been coated with a film of air.

The proper amount of water with the pulp on No. 1, and the proper amount of water in No. 2 being fixed, the carrying over of the clean concentrates past the jets of No. 2 should be accomplished and regulated by the uphill travel only.

Frequently the sand and water on the belt will be distributed *unevenly*, the sand working to one side of the belt, and making a heavy, broad corner, while the other is sloppy. To control and remedy this, see first that there is no jar about the machine; that there are no loosely working parts, that everything is working noiselessly, and that all the parts are in line. If, then, there is not an exact balance of the pulp on the belt, the heavy sand corner forms on one side or the other. To adjust the *load* and keep the sand evenly distributed on the belt, the lower bearings (*b*) of all the uprights (N) on one side of the machine, are moved forwards or

backwards by slight blows of the hammer. The change of position from the vertical of N, etc., thus occasioned affects the pulp on the belt; and by changing the position of *b*, etc., on one side or the other, the right balance or equilibrium will be obtained, and the sand and water (or pulp) will be uniformly distributed across the belt; *e.g.*, if the heavy sand corner is on the shaft side move the bottom bearings (*b*, etc.), on the opposite side, *out*.

Again, the sand corner can be partly controlled by bending the end of the driving spring that is fastened in the collar towards the side having thickest sands.

The same effect, and even more positive, is produced by moving the crank-shaft (and with it the table) the same way as the end of the driving spring is bent.

The underneath rolls have also some effect on the corners, by swinging one end of each either towards one another or in the opposite direction.

The water in the concentration box is constantly agitated by the motion of the belt, and consequently the water escaping from this box carries in suspension quite an amount of very finely divided sulphurets of high assay value. To save these there should be used settling boxes (Nos. 7, 7, 7) which can be cleaned out once a month, and a product obtained which will add materially to the value obtained from the ore. Two men understanding the machine can put it together in a few hours.

Regarding the bearings of A A—those of the head roller are *higher* than those of the foot roller. The head roller is a little higher than the regular plane of the table, and it is also advisable to raise the small roller and its bearing next to it, by a piece of wood. This additional elevation enables us to use less water at No. 2 than would be otherwise necessary.

The lower edge of No. 1 should be within an inch of the surface of the belt (E).

Price, Weight, Water, and Capacity.—The price of each machine is $575, at the works in Chicago or on vessel in New York, but in this price are not included the parts represented by the Nos. 3 and 4. These parts are generally built at the mill, but will be furnished by the makers if so ordered, at cost price $18; and their weight, ready for shipment, will be about 500 lb. The machine proper, boxed ready for shipment, weighs 2240 lb., and no part weighs over 160 lb.

For one machine from 1 to 1½ gallon of clear water per minute is used at the head, and from 1½ to 3 gallons per minute with the pulp.

The boiler for a 5-stamp mill, with 2 concentrators, calls for 1 gallon a minute; hence, in places where water is extremely scarce, 2 gallons a minute *can* supply 5 stamps, 2 Frue ore concentrators, and the boiler by settling and pumping back.

As regards the capacity of the Frue ore concentrator, late practice demonstrates that about 6 tons per 24 hours, passing about a 40-mesh screen, is as much as it is advisable to treat. If a battery of five stamps does its duty, the quantity crushed is largely in excess of 6 tons; for this reason the best practice is to put 2 Frue vanners to 5 stamps, if the stamps are heavy and the sulphurets are high grade and difficult to save. Where pulp from 5 stamps is fed to two machines, the pulp is divided, one-half passing on each. The machines are generally placed in a double row on the same level, head to head, so that the attendant overlooks both rows in walking between; the concentrator floor should be so far below the level of the battery as to allow the feed launder to be above the head of the attendant.

In many cases 3 Frue vanners to 10 stamps will yield entirely satisfactory work, and where the gangue is light, or the stamps not heavy, one is sufficient to treat all the ore crushed by 5 stamps. In one case in California 8 vanners are treating all the ore from 40 stamps, the tailings assay nothing, and the entire cost of milling is under $1 per ton.

A great feature of the vanner is that no sizing of the pulp or slimes is necessary; they pass direct from the stamps on to the copper plates if these are used, and thence on to the vanner.

In some cases it is desired, either as a security against loss from careless work at the battery or in the treatment of special gold ores, to save amalgam as well as sulphurets on the concentrator. For this purpose a special device is needed, and very simply applied either to vanner or Embrey machines. An amalgamated copper plate, 3 ft. to 8 ft. long, is attached to shaking frame, and across it, at bottom and top, low cleats are nailed, forming riffles. This device is found the most effective possible for catching amalgam; hard amalgam is caught in the riffles and by the shaking motion rolled into small pellets, which are collected at intervals. The copper plate itself by the shaking motion becomes an excellent addition to the amalgamating apron at battery, and at several mills valuable returns are obtained in this way. We may mention one small mill in New Mexico, where from $150 to $200 per day is cleaned up from these shaking feed coppers on vanners. The amalgam saving device is supplied with either side or end shake machine if desired, in place of ordinary pulp distributers.

The vanner can be used for the concentration of almost any ore, the only point of great importance being that there is a fair difference between the specific gravity of the mineral to be saved and that of the waste matter with it. The following minerals have been worked upon with excellent results: Iron and copper pyrites, arsenical iron pyrites, zinc blende, galena, tin stone, cinnabar, native silver, carbonates of lead and copper, tellurides of gold and silver; and in the case of "tailings" from amalgamating mills, "floured" quicksilver and slimes from settling

tanks have been experimented upon, and made to yield the impalpable mineral they contain. There are several of these machines at work at the St. David's Gold and Copper Mines near Dolgelly, Wales.

The Improved Frue Vanner.—In the vanner which has just been described the belt was quite smooth, and, indeed, this form of belt is, perhaps, the best for saving fine slimes, as compared with one with a roughened surface. It has been demonstrated, however, that a certain form of belt surface has an important effect, allowing the use of a steeper inclination and more water, and as a consequence greatly increasing the capacity. Indeed, it is stated that after a comparative trial of several months between the two types of machines, the one with a special belt was able to treat as much material as two with a smooth one, to which must be added the saving in first cost, erection, space, power, and surveillance.

The form of the machine itself is not altered, with the exception of some slight modification; the essential difference is in the belt itself, which is both heavier and more costly,—the price of the new type of machine being £165 or $825, as compared with £112 or $575.

There are, however, certain differences in the manner of erecting and running the new machine, which may be summarised as follows:

Directions for Setting Up.—Rollers.—As the belt is heavier than the old style belt, and carries a heavier load just below the pulp spreader, a few extra small supporting rollers are introduced on the shaking frame.

Inclination.—In the old style machine there is an increased inclination to the upper end of the belt as compared with the lower part. This extra grade at the head is still further increased by about $\frac{1}{4}$ in., which is provided for by the relative heights of roller bearings in the new machine.

Water Distributer.—This is practically the same as that in the regular style of the machine. The jets should be spaced, however, to correspond with the class of pulp being run. For the average pulp from a stamp mill the jets should be about $2\frac{1}{4}$ in. apart. The distributer is placed from 1 in. to 2 in. higher up towards the head of the belt than in the old machines, owing to increased inclination here. The distributer is also raised somewhat higher above the belt so as to give a drop of about $1\frac{3}{8}$ in. from the spouts to the belt surface, giving in this way a little greater efficiency from increased force of impact.

Pulp Distributer.—This should be somewhat flat and as close to the belt as possible, so as to make a gentle delivery without force on to the belt.

Speed.—The number of revolutions of the crank shaft may vary from 180 to 210 according to the class of pulp being worked. For ordinary stamp mill crushing, from 195 to 205, should be the limit in either direction.

In arranging pulleys, calculation should be made from the minimum

speed when the power is variable, so that in no case will the machine run less than 194, and any variations will be by increase not decrease of speed—work being less affected by the former than the latter.

The forward motion of belt will depend on inclination and ore somewhat, but should usually be about 29 in. to 36 in. per minute.

Directions for Running.—The improved vanner, besides being used to take the pulp direct from the stamps on all ordinary milling ores, can be used with special advantage on all concentrating ores, where the pulp is sized. It will handle all sizes from No. 10 mesh to the finest slimes, doing the best of work and having a large capacity, replacing fine jigs, concentrators, and slime tables.

It is also especially adapted to ores carrying a large percentage of valuable mineral.

When the belt is to be used for concentrating sized pulp or very heavily mineralised pulp, special directions should be obtained for setting up and running. For all ordinary work the following directions will be adhered to.

General.—The necessity for firm setting up, accurate adjustment, regularity in speed and water and pulp supply, as well as the importance of *perfect cleanliness*, applies equally to the new as the old machines, and full directions are published on the subject.

The special directions to be noted in adjustment of the improved machine are as follows:

Described generally, it can be said that the new machine requires more wash water and inclination, and a less bed of pulp than the old machine.

Inclination.—An average inclination of the machine should be from 3 in. to 5 in. in 12 ft. This may be increased to 10 in. in the case of coarse sized pulp, or diminished to $\frac{1}{2}$ in. in the case of absolute slimes. As a rule, the machine should first be set a trifle steep; and then, with a normal speed, of say 200 shakes, and a good flow of wash water from the water distributer, the inclination should be decreased little by little till a slight bed of pulp is formed on the belt, so that by putting the hand into the flowing pulp the grains of sand can just be felt slowly rolling down the belt, and can be picked up between the fingers. This bed of pulp will be more apparent just below the ore distributer, but lower down the belt should be less. Any indication of stickiness or of a heavy bed settling in the depressions means poor work.

Battery Water should usually be as light as is consistent with good work on the copper plates where these are used before the concentrator; and in this connection it is worth while stating that full-width coppers should have an inclination of $1\frac{3}{4}$ in. to 2 in. to the foot. If used too flat, they need too much water to clear them of sulphides. The pulp should fall gently on to the belt, and be well distributed across it. The

distributer should be as close down to the top of the belt flanges as possible, and be placed as flat as practicable for a free flow of the pulp over it.

Wash Water.—More of this is required than on the plain belt, but of course not in excess of what is required to make clean sulphurets. The quantity varies from $1\frac{1}{2}$ to 3 gallons per minute. Ordinarily the lower edge of water distributer should be fully $1\frac{1}{2}$ in. above belt surface, so as to give this extra force to the falling streams; but on fine crushing or very slimy ores, the jets should be closer together, and the distributer set nearer the belt.

Forward Motion of the belt should be kept *slow* (a normal speed is 32 in. per minute), and is less used as a means of adjustment than with the plain belt, the travel usually being only increased if percentage of sulphurets is unusually large, and a large quantity of pulp being treated, and in this case the belt will probably require more grade and a faster shake.

Having the machine now in good order, running at say 200 revolutions, battery water normal, and the belt at such an inclination that a light bed of pulp is beginning to form, the following points are to be observed:—

If the concentrates are coming over clean, the inclination of belt may be decreased a little up to the point where such a decrease involves impure concentrates; but, as a rule, a light bed with clean concentrates means the best general work of the machine, and small value in the tailings. In case of bed getting heavy, or concentrates carrying too much sand, a slight increase of speed will remedy both defects. Variations in character of ore, and size of crushing, involve slight changes in the minimum speed to be used; but when this is once determined the machine will run regularly, giving clean sulphurets, and requiring only attention to wash water and oiling.

The wash water distributer must be kept clean, so that the streams remain constant.

If the concentrates carry sand, and the bed of pulp is heavy, while the speed is normal or fast an increased inclination of belt is necessary.

If the concentrates carry sand and bed of pulp on belt is light, an increase of speed, with perhaps decrease in inclination, is desirable.

Use wash water more liberally than with the plain belt; but too great an excess will bank up sulphurets and sand below distributer, and the two will go over together. In this latter case increase speed and decrease wash water.

Keep the bed light rather than thick or pasty, and refrain from changes in speed or forward motion of the belt, trusting almost entirely to speed of shake, inclination, and wash water to regulate the work of machine.

As a rule, a very slimy pulp requires less inclination, a slower shake, and more battery water than a cleaner and more sandy pulp.

The General Principles on which the new belt must be regulated are as follows:

1. The pulp and water flowing down the belt is prevented from actual settling by the shaking motion. This motion or agitation must be such as to just allow the pulp to settle, but not to pack or stick; and this consistency allows the particles of mineral and coarser sand to sink into the depressions of the belt surface.

2. The inclination of the belt regulates the speed of the down flow of the water. This last should be just such as not to disturb the settling due to the shaking motion, but just enough to keep the lighter particles of sand flowing slowly down the belt from one ridge to another, keeping this flow up to the quantity of pulp coming on. In this way, by using a shallow bed or stream of pulp, the separation of mineral is a continuous one, and over a series of *rising surfaces* which only permit the lighter particles to go over them. For this reason a deep bed or a sticky, thick pasty bed does not permit of this method of separation, and the depressions in the belt become overcharged with coarser sand, and soon spoil the concentrates by carrying the load past the water jets. It follows that to get the benefit of the new belt we must have a *quick shake*, a *shallow bed of pulp*, and a *fair grade*.

3. At a normal speed of belt travel—say 32 in. per minute—the new belt will carry up, without overloading the depressions, at least 1000 lb. of sulphides in 24 hours. A faster speed is therefore in few cases necessary. An increase in speed of belt travel should only be resorted to when an accumulation of sulphurets is noticed on the belt below the ore spreader, and then only a *very slight* increase is sufficient; and, moreover, such accumulation of sulphurets is usually due to machine being run too slow or too flat.

A good general plan of starting the belt on a new ore is as follows:

Set the frame with a fall of 4 in. on the 12 ft. ($\frac{1}{3}$ in. to foot), give a speed of 200 revolutions per minute to crank shaft. Give good fair streams of water to water jets of water distributer. See that stamp battery is using no more water than necessary for copper plates; allow the machine to run 15 or 20 minutes; the sulphurets come over at once. The bed of pulp is then examined by the hand, just behind the ore spreader, and should be of such a consistency that the heavier grains of sand can be felt under the fingers slowly rolling down the belt, and by closing the fingers together some of the grains can be caught between them. If a sticky bed is forming on the belt, increase the grade a little, and in case the ore slimes badly, an increase in battery water may be necessary; but if there is no bed only a thin and rapid stream of water and pulp, the grade is flattened till the right consistency

of pulp is obtained. Of the two extremes, insufficient bed is preferable to too heavy and sticky a bed.

Having the pulp right, the sulphides next claim attention. The "field" of sulphides should be thin, and the sand covering should not extend up to the water distributer. This is arranged by regulating the water jets. If gangue is heavy and works up too far under the water distributer, increased speed of shake is necessary, and this may allow of a slight flattening of grade.

The belt must be set true without jar in running. No sand corners form as with the plain belt, but they are indicated and must not be "sloppy." If speed of mill slows down, forward motion of belt must be stopped at once or sand will come over and spoil the collected sulphides. If mill is stopped, the belt should be cleaned off to prevent the sulphides *rusting* into the depressions. If this last does occur clean well with a soft bristle brush, moving it from side to side.

These vanners have come into general use on all the gold fields of the world, including the Welsh one, where there are several vanners at work at the St. David's Gold and Copper Mine, near Dolgelly, North Wales, where also a plant for the concentration of the slimes from the amalgamating plates, on the Elmore oil system is being created.

CHAPTER XVIII.

FINE CONCENTRATION MACHINERY (continued).

The Embrey Concentrator—Description—Operation of the Machine—Directions for Working—The Lührig Vanner—Operation of the Vanner—Concentrating Tables—The Wilfley Table—Hallet Table—Bartlett Concentrator—The Lührig Table—Tin Dressing in Cornwall—The Clitters Tin Concentration Mill.

The Embrey Ore Concentrator.—The side shake which is the peculiarity of the Frue vanner is, perhaps, not altogether suited to every variety of ore, and so in the Embrey concentrator this is replaced by an end shake of from 200 to 220 per minute, which is found to be sufficient to prevent the slimes and pulp from settling on the surface of the belt before the separation between the rich material and the steriles is effected.

The machine consists of an endless belt (E), fig. 230, with flanges on its edges, supported on rollers in an inclined position, and having two motions, one a slow revolving one up the incline, the other a vibratory shaking motion imparted by a crank or eccentric shaft to the frame carrying the supporting rollers.

By reference to the drawings (figs. 230, 231 232) the construction and action of the machine can be readily understood. G G is the main frame, consisting of two sides, made up as shown of cap, sill, posts, and two braces, all bolted strongly together. These two side frames are joined together by cross sills and bolts at the bottom, and long bolts with collar, shoulders, inside at the top, as indicated in the drawing.

The framework, when erected, makes a stiff support for the whole machine, and can be set on an ordinary floor, and blocked up at the front end if desired, for variations in the inclination of the belt when necessary.

The frame should be placed in such a position that the head or upper end of the machine where the water distributer is, stands in a good light and with a clear space in front of at least 4 ft., or, better still, 5 ft. if possible. It is at the head of the machine that the concentrations are collected, so that the importance of light and space can be understood. At the lower end the only clear space required is that sufficient for passing round the machine for oiling, etc., and 2 ft. is ample for this.

Within the main frame a light shaking frame (F) is supported, on which the belt is carried. This frame (F) consists of two sides of wood with cross braces and bolts, and carries at each end a set of bearings in which the end rollers (A A^1) revolve. Between these end rollers a number of small galvanised iron rollers (D D) are carried in bearings on the shaking frame, and with the end rollers form an inclined plane on which the upper or working surface of the belt (E) is supported. The belt (E) is made of rubber with canvas filling, has soft flexible rubber flanges around its edges to prevent the overflow of water from its surface, is $27\frac{1}{2}$ ft. in length and 4 ft. in width. This belt is a special article of manufacture, which has taken several years to perfect. Any defects in its construction or impurity in material used involves a rapid wear of the belt, and the cost of renewal is high. Experience has shown that perfect belts will last with constant service from three to six years if properly cared for. The shaking frame is supported on six legs or toggles (N N) which stand in adjustable stirrups (*b b*) hanging on the main frame, and which are used sometimes for slight changes in inclination of frame or levelling of the belt across. The shaking frame (F) is connected by short connecting rods (R R) attached to the lower roller bearings, to two eccentrics having about $\frac{3}{4}$ in. motion, and fixed on driving shaft (H). This driving shaft is fitted with tight and loose pulleys (I) which can be driven by a 3-in. belt from broad-faced pulley on any convenient

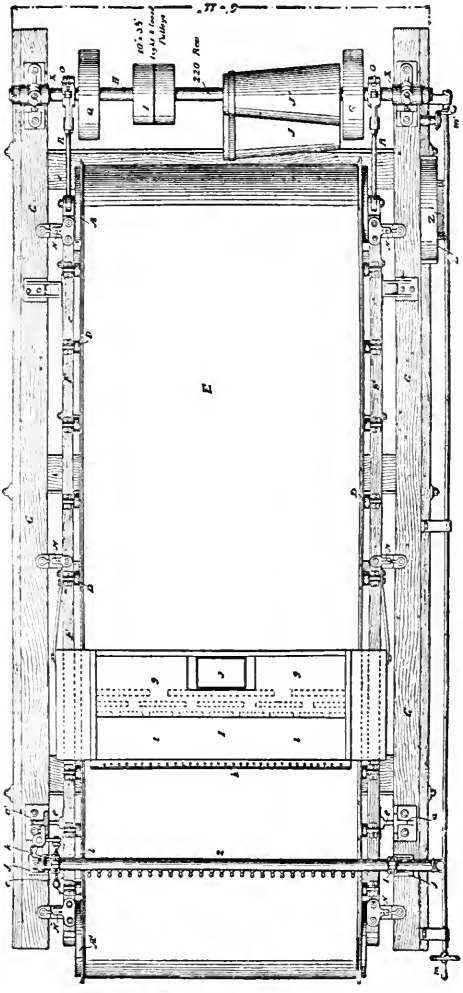


FIG. 230.—PLAN OF THE EMBREY CONCENTRATOR.

shaft in the mill, or from a special countershaft put up above the machine. There are two small flywheels (Q Q) on the driving shaft, and also a cone pulley (J[1]), which is connected by narrow leather belt to a corresponding cone pulley (J) on the shaft below. The speed of this lower shaft can be regulated as shown by the belt shifter (m^2) actuated through the small bevel gear and screw (m^1) by means of the hand-wheel and rod (m) at the head of the machine. The motion of this lower shaft is communicated by the bevel gear to the worm (Z) which in turn gives a slow revolution to the worm gear (L) on shaft of roller (B[1]) around which the endless apron plies. The effect of the revolution or worm gear (L) with its attached roller (B[1]) is to give a slow travel upward of the rubber apron (E) on which the concentration is effected, while at the same time the eccentrics on the driving shaft give the upper surface of the belt, through its supporting frame, a rapid but steady vibratory or shaking motion. The belt has therefore two motions: a slow forward motion, and a rapid vibratory motion, the effects of which will be explained later.

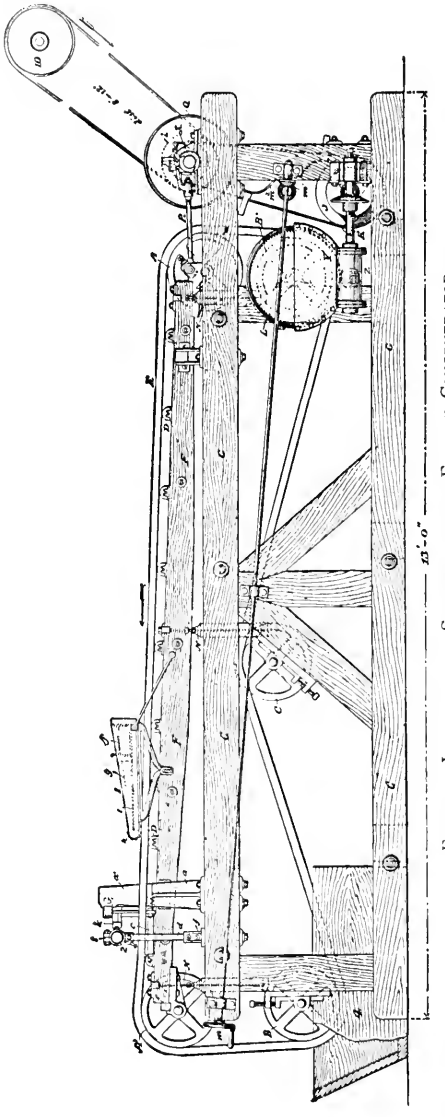


FIG. 231.—LONGITUDINAL SECTION OF THE EMBREY CONCENTRATOR.

The endless travelling belt is kept in position below by the three fixed rollers B), C, B[1]), of which C serves as a tightener, and in part as a regulator of the travel of the broad belt in keeping it straight on the shaking frame above. This latter object is also served at need by the

adjustable bearings of the rollers (A[1] B) which, by tightening on one or the other side of belt, causes it to travel to one or the other side of its course, and so admits of neutralising any tendency to run off the supporting rollers. The lower front roller (B) dips into a tank of water (4) so that the belt in passing around it is submerged for a short time, so as to wash off any adhering concentrations which collect in the tank (4).

On the upper side of the main frame (G) are four short cast iron standards, with projections inside which serve as guides to the sides of the shaking frame, so that its motion is simply in the line of its length without any side play. One of these standards (a^1) is higher than the other three, and serves a double purpose: its upper part being used as a support for a bell crank (k) which is attached by a strap connection (c) on the inside to the shaking frame (F). The outer arm of this bell crank (k) is attached to one of two clamps (1) on the movable water pipe (2) which stands on two spring legs (d d) bolted below the sockets (ff). This water pipe (2) is fitted with a number of small jet cocks on its under side, and at one end is connected with water supply by a flexible hose coupling to allow of its motion by the bell crank (k). The effect of the spring leg support and bell crank attachment to the shaking frame, is to give the pipe (2) a rapid shaking motion across the width of the belt (E) and coincident with the longitudinal shake given by the eccentrics (o o).

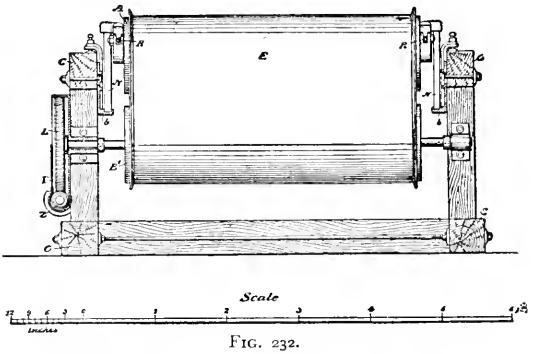


FIG. 232.
FRONT END ELEVATION OF THE EMBREY CONCENTRATOR.

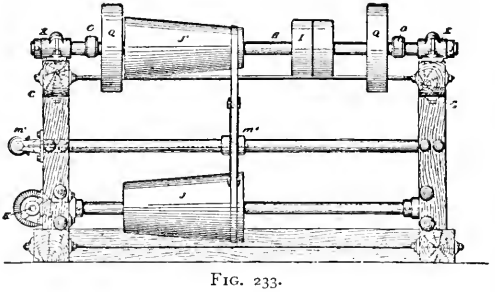


FIG. 233.
BACK END OF EMBREY CONCENTRATOR, SHOWING DRIVING GEAR.

No. 1 is the ore distributer which receives the material to be concentrated, and spreads the same over the width of the belt. It is constructed as follows: The body of the distributer is a low open frame or box, with bottom, back, and two sides, but open in the front. At the front end there is a turned-up lip of sheet iron (h) with a number of

holes punched along its bottom. G is a board with strips of wood attached on its lower side, arranged as shown by dotted lines in the plan. These cleats or buttons are arranged so as to break up the current of water and pulp flowing around them, spreading the same evenly over the whole width of the distributer. At the back end of the spreader board (*g*) there is an opening into which is placed a small copper tank (*j*) which receives the flow from any launder or pipe of the pulp to be treated, and serves to retain any quicksilver or amalgam in the case of gold milling. In working gold ores, an electro silver-plated copper plate (*i*) is placed on the distributer, and under the spreader board (*g*). This plate with the copper tank (*j*) constitutes what is called an amalgam saver, and can be added to the machine at an additional cost of $30, when desired.

Operation of the Machine.—The arrangement of supporting stirrups and shaking frame (F) gives the latter and the belt it supports a slight incline when the main frame is placed level on the ground. This inclination can be readily increased or diminished by blocking up one or the other end of the main frame (G). This blocking is best effected at the upper end, as not interfering then with the driving belt to the pulley at the lower end. Supposing the inclination of the belt to be adjusted, the operation of the concentrator is as follows:

The crushed ore—not coarser than 30-mesh and preferably 40-mesh size—in a small stream of water falls on to the distributer (I), thence is spread evenly over the full width of the belt (E) and flows gently down the incline to the lower end of the machine. The belt is subjected to a steady rapid shaking motion in the direction of its length, by the revolution of crank-shaft (H), and at the same time it has a slow forward travel up the incline, communicated by the cone pulleys (J J^1) and worm gear (L). The effect of this forward travel is to carry up all heavy particles of ore which settle on to the belt, in the passage of pulp down its surface, assisted by the shaking motion. This shaking motion by keeping all the pulp in gentle agitation, prevents the sand from packing on the belt in a mass—as it would do otherwise on so slight an incline with the small quantity of water used—and causes the heavier mineral particles to settle down to the belt, while the lighter waste rock is kept suspended in the flowing water, and passes off at the lower end as waste or tailings. The forward travel of the belt carries up to the water distributer (2) all the heavy mineral particles, and here by the action of the many small jets of clean water falling on the belt, a final separation of the clean mineral from any adhering rock particles is effected. The mineral is carried past the jets of water by the revolving belt surface to which it adheres, and is deposited in the concentration tank (4) where it is washed off by the passage of the belt through the water, as shown in the drawing. At intervals the concentrations are

scraped out of the tank (4). The lighter rock or waste and muddy water, constituting the tailings, flow off the lower end of the belt into a suitable trough, which carries them out of the building.

Directions for Working.—The machine, when set up square, firm, and with all bearings in proper condition, should run *easily and noiselessly.* The concentration tank (4) should have always sufficient water to properly immerse the belt as it passes around roller (B), and should be built with sloping front as shown, to facilitate the scraping out of the concentrates at intervals as they collect, to prevent accumulation and rubbing against the belt from a pile below it. The front of the tank is better with a flatter slope than shown in the drawing. The main frame (G) should be firm and free from motion.

The inclination on the length of belt is usually about 3 in. Speed of crank-shaft (H) 200 to 220. The lower speed is preferable if satisfactory work can be accomplished by regulation of inclination and forward speed of belt. Having a fixed inclination and speed of shake, small jets of water are opened from distributer (2) using as little water as possible, and then the chief means of adjusting the delivery of concentrates should be by the forward speed of belt through hand wheel (*m*). On some ores the shaking water distributer will be found a great improvement, on others the water pipe can be disconnected from the shaking frame and remain stationary. When the water distributer is in motion, less water is required to make clean concentrates than if stationary.

The material treated on the machine should not be coarser than 30 mesh, *i.e.*, should pass a wire screen of 30 holes to lineal inch. In case of coarser crushing, jigs should be used for all sizes above 30 mesh. The usual size for this class of a concentrator is 40 mesh. In regard to quantity, the machine can be calculated on from 6 to 10 tons per 24 hours, and, therefore, either one or two machines are used to each 5 stamps, according to character of ore and closeness of concentration required. If one machine only is used to 5 stamps, the belt should be placed flatter and with a faster forward motion than if the pulp be divided between two machines, owing to the large quantity of water. In case it should be necessary to settle away the pulp from an excess of water, large pointed boxes are used with continuous discharge from the bottom, and overflow of clear water from the top.

In regulating the forward motion of the belt, the steady delivery of clean mineral is the point to be aimed at. If sand is seen coming over, the forward motion is reduced; if mineral collects in quantity below the clear water jets and spreads down the belt for some distance, it shows that discharge is not as rapid as it should be, and belt should travel faster. In the best work clean mineral should come over, and sand be seen clearly over the mineral two or three inches only below the water jets.

The quantity of clear water used is from $\frac{3}{4}$ to $1\frac{1}{2}$ gallon per minute. The quantity of water coming on with the pulp is usually from $1\frac{1}{2}$ to 3 gallons per minute.

It is of great importance to keep the concentrator absolutely clean. No splashing around of pulp must be allowed, or belt and bearings will soon be ruined. It is the care taken in keeping all parts clean, and play in joints taken up, that determines not only the life of the machine, but the character of the work done by it. *Speed should be regular*, or action cannot be automatic, and clean mineral cannot be made, and it is equally important that ore feed and water supply should be regular. With ores producing rich mineral concentrates, a perforated water pipe should be placed under the belt just above and at the back of the concentration tank (4) so as to wash back any mineral which might cling to the belt as it leaves the water. This arrangement necessitates an overflow from the concentration tank, which should be near the *front end*, and should discharge into a settling box with at least one partition dipping below the surface, to prevent loss of floating mineral. This settling box is easily made of 1-in. boards about 6 ft. long, 10 in. wide, and 8 in. deep, and can be placed along one side of the machine on the floor, receiving the tank overflow at one end, and discharging from the other into the tailings launder at lower end of concentrator.

The concentration tank (4) should be scraped out at intervals with a hoe into a lower box placed under the lip of the tank. In some cases a low flat car on wheels is used, and run from one machine to another, receiving the scrapings of the various tanks till full, and then taken to the drying floor.

It is well to see that the first small roller (D) at the upper end is sufficiently raised by its bearings above the frame, to just touch and support the belt, so as to prevent any flapping up and down of the latter, which would prevent good work. At the same time this roller should not be so high as to unduly raise the belt at this point from the general plane. The regulation of this roller is easily effected by loosening the screws of its bearings, and putting under the latter small strips of wood or rubber, till the proper height is secured.

To recapitulate the most important points to be observed in running the concentrator:

(1) *Perfect regularity in feed, in speed, and in water supply.*

(2) *Perfect cleanliness of machine.* All woodwork as well as ironwork should be gone over every day by the man in charge, and all sand, dirt, or oil drippings removed.

(3) Proper attention to bearings, reasonable oiling, and taking up all the looseness or play. This includes, of course, watching the eccentrics to prevent play or heating.

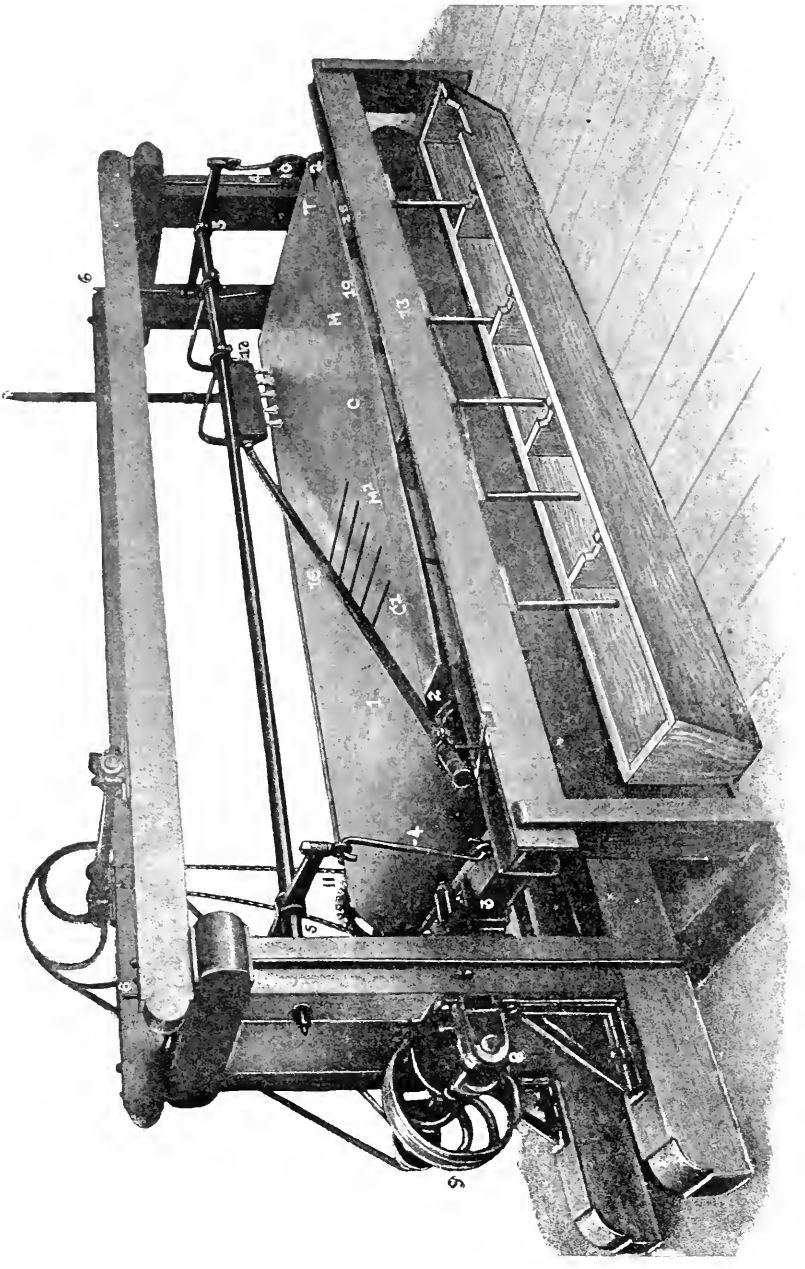


FIG. 234.—THE LÜHRIG VANNER.

(4) Avoidance of excess of water at head of machine as well as with pulp.

(5) Regulation chiefly by forward motion of belt, after once adjusting inclination and water supply. If it be attempted to regulate by water at head, too much attention is required.

The shipping weight of the machine is about 2800 lb.

Full instructions and working drawings are sent out with both the Frue vanners and the Embrey concentrators, so that a mine manager, even if as yet unfamiliar with the machines, should have no difficulty in erecting them and getting them to work.

The Lührig Vanner.—This machine, with which I have had a long and successful personal experience, combines the best features of the percussion or bump table with the advantages of belt vanners.

It will be seen from fig. 234 that the machine is a side delivery vanner, having an endless rubber belt (1) supported by small rollers underneath the belt, and running over two larger end rollers (2). The rollers are fixed on a frame (3) which is suspended by means of S hooks (4) to two supports (5). These supports can be raised or lowered by means of screw handles (6), thus allowing the whole frame to be tilted as desired. The frame carrying the belt is set level in the longitudinal direction, and at an inclination transversely sloping down towards the front.

The cam (8) on the shaft with driving pulleys (9) revolves 75 to 100 times per minute, thus imparting 150 to 200 strokes to the belt frame, which is pushed back into position by the spring (10) at the other end.

One of the end rollers (2) is driven by a chain gearing (11), thus causing the belt to travel slowly from right to left. The ore pulp is fed through a feeder (12) on the right-hand top corner on to the belt. The feeder is provided with a line of holes distributing the pulp on the belt. The pulp passing through the holes is thus delivered very closely on to the belt. Any air bubbles, which so frequently cause the float metal to be carried off with the slime water, are broken up, and the flow of the water down the belt is also checked to a certain extent.

In front of the vanner is the receiving launder (13), into which the various products flowing down the inclined belt are discharged, and thence delivered into separate receptacles through the down pipes shown in the illustration.

A spray pipe (16) having small holes through which the necessary clear washing water is supplied on to the belt, is fixed diagonally across the belt.

The vanner is set to work by the driving pulley (9) the power required being only about $\frac{1}{3}$ horse power. The number of revolutions

varies, according to the character and size of pulp, from 75 to 100 per minute, and can easily be determined by experiment. The driving gear (11) causes the belt to travel slowly from right to left, the cam imparting at the same time 150 to 200 blows or strokes per minute. The speed of travel is about 8 to 10 ft. per minute, and can be easily regulated to suit the ore pulp, coarser sands requiring a somewhat greater speed than fine slimes.

The water supplying the spray pipe (16) being turned on, and after the belt is thoroughly wet, the pulp is fed on to the belt through the feeder or pulp distributer (12).

As soon as the pulp gets on to the belt, the separation of the component minerals begins, the lighter gangue or waste being carried down the incline into the receiving hopper for the tailings, the heavier minerals or metals remaining on the belt. The latter are carried by the forward movement of the belt, towards the clear water pipe (16) and here washed, travelling parallel to the spray pipe and separating according to their specific gravity, the heavier remaining next to the pipe until they are finally washed off at the end of the pipe into the receiving launder (13).

The strong kick or stroke imparted to the frame keeps the minerals and gangue in the pulp loose, and the clear water washing over the solid material keeps a thin film or sheet of water over it, which prevents the metal floating off on the surface of the water. At the same time, the hard kick throws the fine float metal, which might have come to the surface, down on to the belt, where it adheres until washed off into the concentrates.

The material being separated into clearly defined and visible streaks of its component parts by the combined action of the vanner and the washing water, the man working the machine can easily regulate the vanner so as to be able to determine the best working conditions for the pulp under treatment. This is effected by means of a series of sliding trays on the receiving launder (13).

The vanner, once adjusted, works automatically, and needs little attention, as its action is clearly visible to the eye.

The great advantage of the Lührig vanner is that it allows of the concentration of slime pulp containing two or more metals, and the separation of the various metals in the same operation.

The following may explain the working of the vanner when treating pulp containing more than one metal where two or more concentrates are to be produced, as, for example, the treatment of lead and zinc slimes, with which I have frequently had to deal on these machines.

The pulp when passed over the vanner would be separated into clean tailings, zinc middlings, clean zinc concentrates, lead middlings, and clean lead concentrates.

The tailings flow off on the side of the belt marked T, the zinc middlings are discharged at M, and the zinc concentrates at C; the lead middlings at M 1, and the lead concentrates at C 1. The various products are cut off by movable slides (18) in the fixed launder (13) which can lead into their several compartments any parts cut from the separated minerals as they are delivered over the plate (19) in front of the vanner belt. The middlings (M and M 1) can either be returned automatically for retreatment on the same vanner, or, in larger plants, are collected together with the middlings from other vanners, and automatically retreated on separate vanners for middlings. It is specially claimed that the formation of middlings is an advantage over appliances which make heads and tails only, the reason being that fine material, separating in layers on streaks, always forms a zone of middlings which are too rich for tailings and too poor for concentrates, and, in the last-named appliances, these middlings must go either into the tailings, or into the concentrates, thus spoiling the one, or being wasted in the other. This is avoided where middlings can be cut off and separated for retreatment.

If one concentrate only is to be produced, as would be the case in saving auriferous pyrites from stamp batteries crushing gold ores, or when treating pulp containing one metal only, the vanner is worked in a similar way, but only one middling product for retreatment is produced, and the capacity of the vanner is larger.

The regular motion of the vanner, and the regular supply of clear water and of pulp, and also the proper consistency of the pulp, are very important factors in securing good results.

The capacity of the vanners varies, of course, according to the nature and fineness of the pulp and its richness in sulphurets. The best practice, working under ordinary conditions, is to put about two vanners to 5 stamps, if the pulp is crushed to pass, say, a 40-mesh screen, with heavy stamps and material rich in mineral. Treating coarser and poor material, the capacity of the vanners is naturally much larger.

The Lührig vanner has been supplied to most parts of the world, and one of its special features is its adaptability to the treatment of almost all classes of ores and materials which are capable of mechanical separation, and I have used it both in the Pyrenees and in Wales on complex ores.

In the case of a mill for the concentration of lead and blende as in the Cwmystwith mill, described on page 455, where I employed 20 vanners with marked success; the system of classification is first by trommels on revolving screens to the jiggers, then by means of spitzlutten or hydraulic classifiers for the fine jiggers, and afterwards by the large spitzkasten shown in Plate XX. (page 458) for the vanners. For gold or tin ores the mineral would first of all be reduced by stamps to say

30-mesh, the sands from which would be treated on Lührig or Wilfley tables and the slimes after passing over a spitzkasten on vanners. It is just as essential to carry out a close system of classification for the sands and slimes, as it is for the coarser ore sent to the jiggers. This is shown in Plate VIII. (page 364) which illustrates the most modern mill in Cornwall for tin concentration, or dressing as it is familiarly called.

In the case of the ore at the Pierrefitte Mines, where I erected some 40 Lührig vanners, great difficulty was found owing to the presence of magnetic iron which has practically the same specific gravity as blende. In order to free the galena from the blende and iron, a heavy kick or bump had to be given, the speed being 45 revolutions or 90 bumps per minute. A clean lead concentrate was thus formed, and a mixed concentrate of iron and blende. This latter was then dried, and the iron taken out by means of a magnetic separator. At a later period I separated the iron first of all by means of a wet magnetic separator of my own design, so that the slimes fed to the vanners contained only lead and zinc.

It is essential to the success of these vanners that the speed should be regular and invariable, and that the supply of clean water should also be regular and arrive on the table, under the same pressure, otherwise constant attention will have to be paid to the taps.

The vanners need but little hand labour, and it is usual to train boys to look after them. The adjustments are easily learnt, and once the table is arranged for a certain ore there is little else to do but to keep it oiled and to clean the spray pipes. The mineral accumulates in tanks underneath, which are emptied from time to time, and the "middlings" or half concentrated ore can be carried in a pipe direct to another vanner placed on a lower level. In the illustration of the Cwmystwith mill in Plate XX. (page 458) it will be noticed that there are two rows of vanners one above the other, the lower row being for the retreatment of the middlings, and, if necessary, the enrichment of the concentrates.

As distinguished from the Frue vanner, the Lührig will make three or more separations at a time, viz., pure galena, mixed galena, and blende for retreatment, pure blende, blende middlings for treatment and waste. The Frue, on the contrary, will on one machine only make concentrates and waste, so that if an ore containing galena and blende is under treatment, it would first of all, on a Frue, be separated into a mixed concentrate of galena and blende and waste, while the mixed concentrate would again have to be treated on a second Frue in order to separate the galena from the blende.

Concentrating Tables.—Since the first publication of this work very considerable progress has been made in the manufacture of machinery for fine concentration, and more especially in tables for the enrichment of sands and slimes. I use the word sands here as indicating the material

which is too fine for jigging and too coarse for vanners; and it is on this class of ore that the various tables do their most efficient work, although, if due precautions are taken as to the previous classification and thickening of the slimes, they can be used as slime concentrators also, their range lying roughly between 10- and 40-mesh.

The Wilfley Table.—The oldest table of this type is the Wilfley, which has come into general use both at home and abroad as a machine simple in construction, easy to keep in repair, and capable of treating a large tonnage per day; several thousand of them are now at work.

The table which is shown in figs. 235 and 236 consists of a flat surface 7 ft. wide by 16 ft. long, covered with linoleum, upon which is a series of riffles. These latter extend nearly the full length of the table on the discharge side, and grow shorter as the feed corner of the

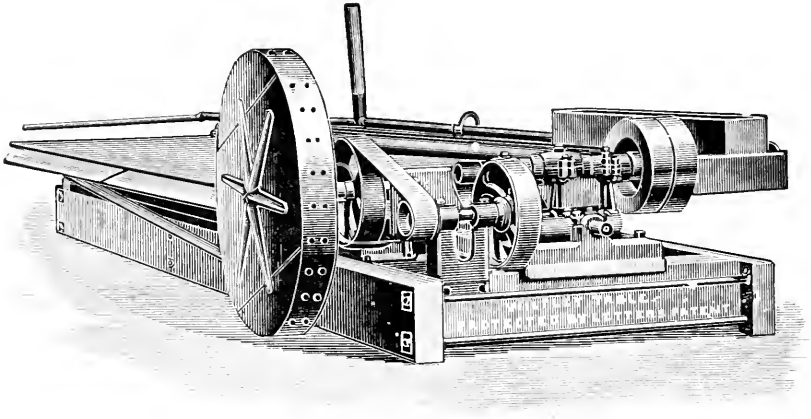


FIG. 235.—THE WILFLEY CONCENTRATING TABLE (DRIVING END).

table is approached. The pulp or slimes are fed upon the table near the movement end and flow down the adjustable inclined surface across the series of riffles towards the tailings discharge. The ingenious movement is so constructed that the table has a quick motion at the outer end of its stroke and a much slower motion at the inner end. This movement causes the ore particles to settle into layers, leaving the clear silica at the top exposed to the action of a stream of wash water, and at the same time causes the entire mass to move up the slight incline of the table towards the concentrates box. The pulp is fed upon the table through a series of small holes in the side of the pulp box. During the entire time it is on the table it is kept constantly under a thin sheet of wash water, which prevents any loss through the mineral floating off on the surface of the water—a frequent source of loss in other tables.

The riffles mentioned above are $\frac{1}{4}$ in. in height at the movement end and taper to a feather edge toward the delivery end. As the pulp moves up the table the upper layer of sand is carried over the riffle by the wash water, while the concentrates are being steadily settled and a fresh layer of sand is brought to the surface. The concentrates, after being freed from the greater part of the sands, move beyond the riffles upon the plain portion of the table where they are washed by a stream of clear water which carries the final particles of silica into the tailings discharge, and also carries the minerals down the table in the order of their specific gravity. Galena is moved but little by the wash water, but by the motion of the table is driven toward the concentrates box. Iron pyrites are carried farther down the table than galena; zinc blende, quartz

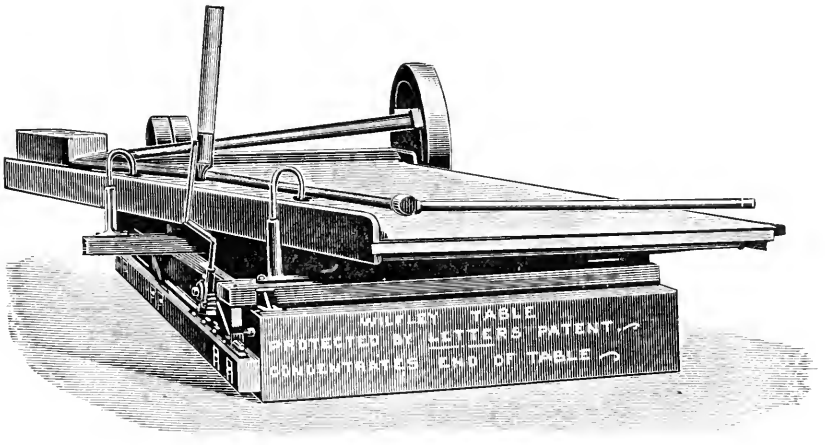


Fig. 236.—The Wilfley Concentrating Table (Concentrates End).

with mineral attached, and clear sand are carried down in the order named. The lines between the various streaks of mineral formed by the combined action of the wash water and motion of the table, are so distinct that it is an easy matter to so adjust the table and wash water that the clear sands are run into the waste spout, and the quartz with the mineral attached, into the middlings spout to be automatically returned to the table by the raff-wheel to be retreated, while all the concentrates are directed into the concentrates box. The table itself runs on small rollers placed underneath, or, in more recent cases, is supported on short vertical toggles.

This feature of the Wilfley table—the separation of the minerals into distinct streaks—is of great value, as, by means of it, the working of the table can be adjusted very closely, and if required the greater portion of any mineral, as zinc, copper, galena, etc., can be cut out.

Another advantage which will at once appear to practical miners is the dryness of the concentrates. The wash water travels in a direction at right angles to the progress of the mineral particles, and goes off with the tailings. The concentrates are only kept sufficiently damp at the discharge to prevent them sticking to the table, and are then in a condition for dumping at once.

I have used these tables in England, and seen them at work in the United States, on galena, blende, copper, and silver ores, and they seem to be favourites with practical mill-men. The shaking motion is produced through an eccentric and a set of toggles similar to those of a stone-breaker, and the power required is small. Full instructions are issued with each table, and they can easily be erected by an ordinary mechanic.

The Hallett Stratifying Table.—This table, which has recently

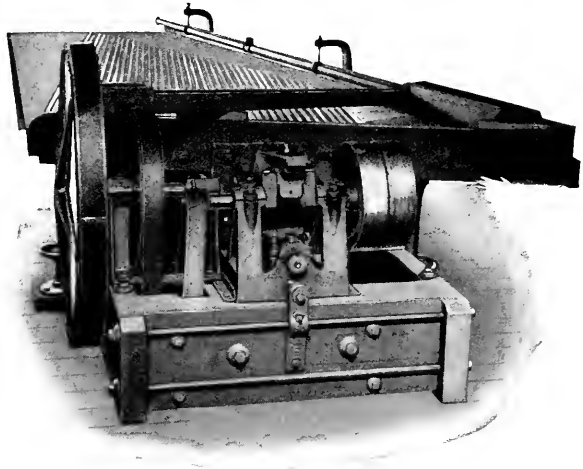


Fig. 237.—The Hallett Stratifying Table.

been put on the market, differs from the Wilfley in several particulars, notably in the way it is supported, the mechanism for driving it, and the fact that its surface is not in one plane. A general view of the driving end of the table is shown in fig. 237. On the right is the feed box; on the left the wheel for elevating the middlings; and in the centre the driving mechanism, of which a side view is given in fig. 238.

It will be noticed that toggles are used for accomplishing the accelerated forward and quickly checked movement as in the Wilfley. The downward movement of the connecting rod actuating the toggles, however, is faster than the upward movement of same, thus assuring a doubly accelerated forward movement with a correspondingly sudden check and an efficient result upon the ore under treatment. This is a

great improvement over other machines of similar construction and insures a longer life for the machine itself.

The top, on which the concentrating is effected, consists of two distinct planes, covered with one sheet of linoleum, forming a firm surface, joined upon the diagonal line which marks the termination of the thin ends of the riffles or tapering strips of wood which produce the concentrating grooves. These tapering strips of wood which form the grooves and in which the concentrating and washing of the ore takes place, are so arranged as to run diagonally with the direction of the motion of the table. This effects a loosening and rapid stratification of the sands, and delivers the residue from the bottom of the grooves to a higher point upon the table for final separation. Thus it will be seen that the roughing work is accomplished in the deeper part of the grooves

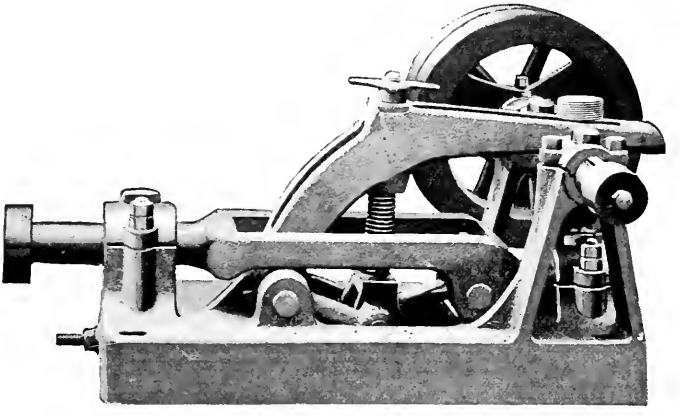


Fig. 238.—Driving Mechanism of the Hallett Table.

and is carried toward completion as the material moves forward under the influence of the differential movement and is delivered on to the unriffled portion of the table for final washing in stratification, according to gravity, which is marked by narrow lines due to the difference in size and colour. After the minerals have passed from the influence of the grooves, they are immediately delivered upon the second plane portion of the concentrating surface, which is set at a slightly different angle from the first plane, with the result that the stratifications that come from the grooves, by reason of meeting less resistance from wash water and from having a new and easier descent to make, are separated into thin wide stripes with the minimum amount of lap and with distinct lines of demarcation, by which it is possible to separate the different gravities of material into separate receptacles with a minimum amount of admixture one with the other.

Again, the surface of this table is adjustable in all directions, and

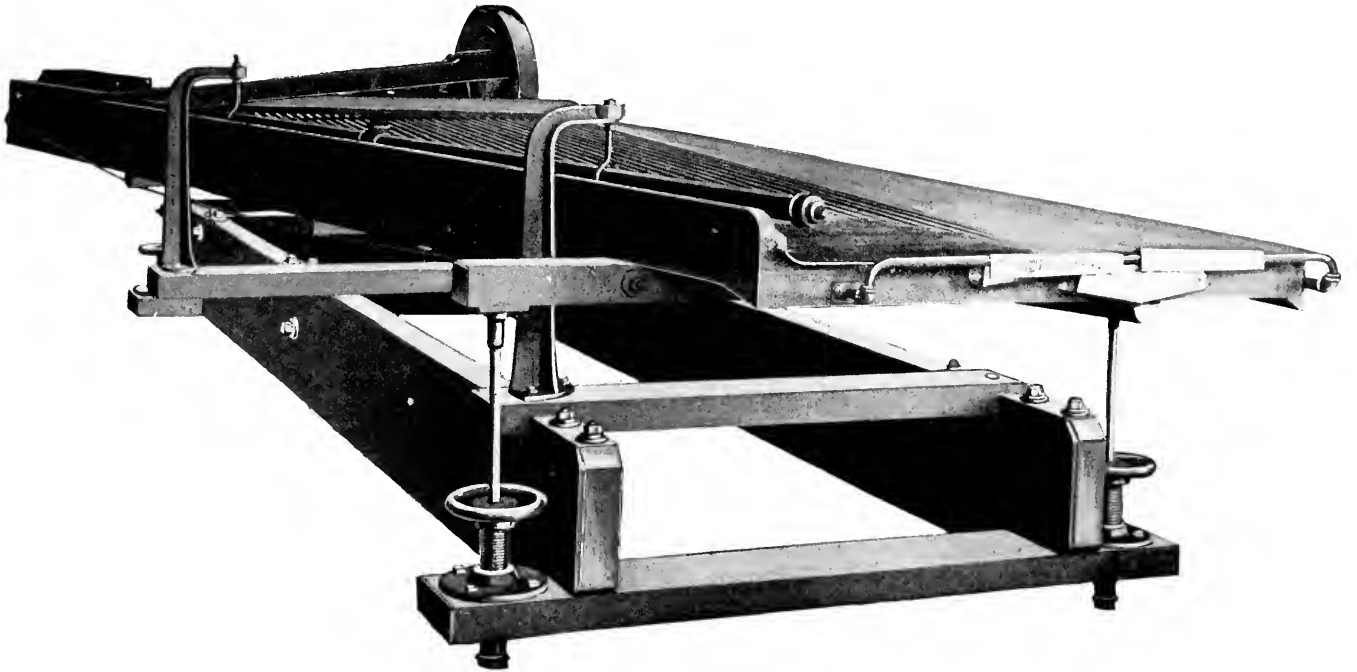


Fig. 239.—End view of the Hallett Stratifying Table.

is usually arranged so that the discharge end is materially lower than the feed end, affording an easy down-hill travel for the material being handled. This greatly increases the capacity of the machine.

The middlings and other launders on the Hallett table slide upon a rail fixed to the discharge end of the table, so that after the table has been brought to primary adjustment by means of the adjustable supports, then the little inequalities in stratification brought about by change of feed or other minor conditions are readily adjusted by changing the launders to suit, that is to cut the sands exactly where the best result can

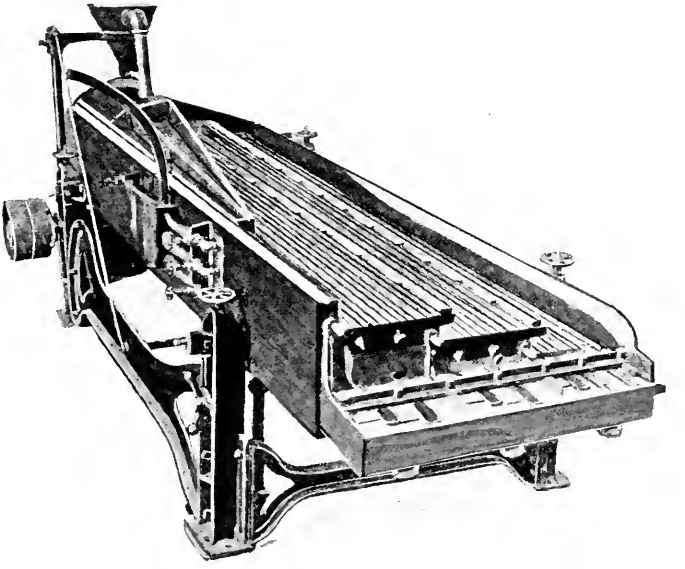


FIG. 240.—THE BARTLETT CONCENTRATOR.

be obtained, without changing the inclination of the table or disturbing the stratifications that have been already obtained. The ore can thus be cut at any desired point by simply shifting the position of the launders, and the amount of material cut out as middlings varied at will.

The elevator wheel is made entirely of metal. The table top is cut off diagonally at its rear ends so as to accommodate the wheel inside of the line of the discharge side of the table. This makes it possible to set the tables nearer to each other, centre to centre, by about 1 ft. as well as adds to the neat appearance of the machine. The middlings received by this wheel can be retreated upon the table, or, if desired, can be passed to regrinding machines.

The Hallett table is carried upon vibrating legs or rods 24 in.

long, and since the movement of the table is but 1 in. at a maximum, it will be seen that the arc in which the top of support travels is very little indeed. It does not set up vibrations in the table top (which break up the surface of the water carried by the table into little squares affecting the sands underneath correspondingly and causing material loss in the tailings) as is the case in all other tables of similar construction to this; nor does it change by wear and become flattened at the points of contact as happens in other machines using small rollers or other devices for the support of the table.

These supports on the Hallett table vibrate within threaded pipes, which are adjustable by means of convenient hand-wheels.

The Bartlett Concentrator.—The retreatment of slimes on the same table, as is the case when elevating wheels are used, is never advisable if it can be avoided, while the use of two or more tables for the purpose takes up room and power. In the new metal top Bartlett table shown in fig. 240, the wooden top covered with linoleum has been done away with and solid metal tops perfectly smooth and rigid in one simple piece have been substituted. Referring to the illustration it will be noticed that the table is built with three separate shelves or terraces, each terrace being riffled, and each having its independent water supply. The pulp being fed at the rear end, travels down the length of the first shelf, by the movement or impulse of the eccentric working against unequal steel springs.

The ore in its passage down the first terrace is subjected to a gentle cross flow of water, and to the shaking or jigging movement of the eccentric; the result is that the silica and light particles of ore are brought to the top and are washed over into the return launders, leaving the heavier and richer portion in the riffles, to be discharged over the front end into proper receptacles. The unconcentrated ore and the tailings return to the second terrace, through the side launders, and the operation of washing and concentration is repeated on the second terrace, and yet again on the third, *thus making a triple concentration on the same machine.*

Every known scientific principle of concentration is at work on the table: jigging, suspension in water, and washing by cross flow of water.

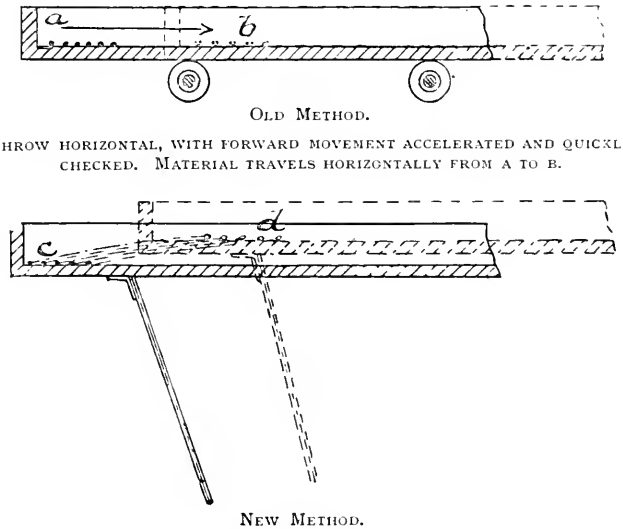
The operation is made unusually sensitive and delicate owing to the fact that the table is under complete control. The water can be regulated on each terrace; the pitch of the table, lengthways and sideways, *and the length of the stroke*, or travel of the ore can also be regulated, all while the table is in operation. Moreover, the concentrates can be cut up or divided into as many grades or classes as may be desirable.

The table is also automatic when once set to fit the ore, and needs no further attention, except to maintain an even feed of pulp and water, and to keep it clean and well oiled in the moving parts.

Particular attention is called to the fact that owing to the small

amount of wash water necessary on the first terrace, nearly all the slimes and fine material are saved there. The inventor has reversed the old order of slime working, and removes these first, using a bedding of coarse ore to protect the slimes from being washed overboard. This is further improved by use of a cone separator which receives the pulp, and divides it into coarse at the head, delivering the excess water and slimes farther along on the table on top of the oncoming bedding of coarse material.

The inventors state that with the Bartlett table no previous sizing or classification of the ore is necessary, and that it will work all ores from No. 3-mesh screen downwards without sizing and yet save the slimes. The size of the machine is 4 ft. × 12 ft., and it can be erected in a couple



OLD METHOD.

THROW HORIZONTAL, WITH FORWARD MOVEMENT ACCELERATED AND QUICKLY CHECKED. MATERIAL TRAVELS HORIZONTALLY FROM A TO B.

NEW METHOD.

FIG. 241.—THROW OBLIQUELY UPWARD AND MOVEMENT REGULARLY RECIPROCATING. MATERIAL TRAVELS FROM C TO D.

of hours, and once set for a particular ore requires but little further attention beyond oiling and cleaning, while it is a substitute for the entire system of jigging and vanning at present in customary use.

I have had no personal experience with this machine, which is manufactured by the Colorado Ironworks Company, of Denver, U.S.A. It is, however, an interesting development of the table type of concentrator.

Buss's Patent Lührig Vanning Table.—This machine is of extremely simple construction, requiring but little attention, and as the working parts are few in number and free from complicated mechanism, it is subject to but little wear and tear. The cost of construction and maintenance is thus reduced to a minimum.

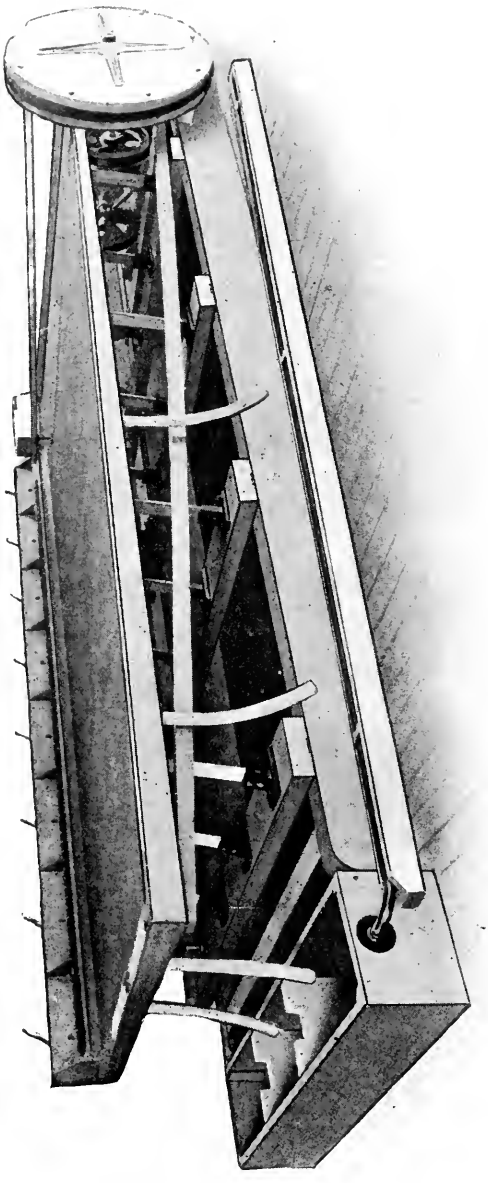


Fig. 242.—Buss's Patent Lührig Vanning Table.

The principle as applied to ore concentration is entirely new, and combines a regular forward movement of the mineral with a slight upward throw, similar to that of the well-known hand vanning shovels, as will be seen from the illustrations.

In the older beltless machines, the movement is obtained by means of toggles, giving a quick forward stroke, rapidly checked, but always in a horizontal line. In this new vanning table, the reciprocating movement is even in both directions, being obtained from a simple eccentric, but owing to the manner in which the table is supported on inclined springs, as seen in the diagrams, fig. 241, the surface receives a slight *upward* as well as a *forward* movement at each stroke. The mineral particles are therefore rapidly separated into layers according to their specific gravities, the lighter

sands being on the top while the heaviest mineral remains next to the surface of the table.

The surface of the table is inclined and can be used either with or without riffles, and a constant stream of water flows across it. This water washes off the barren upper layer into the tailings launder, while the heavier middlings being carried further along the table, follow next into another division of the launder, and are returned automatically by means of an elevator, shown in fig. 242, for retreatment. The heavier ores having a higher momentum than the lighter particles, travel faster than the latter, and are carried still further along the table, being washed off at the end of the table into separate launders which take them to suitable settling tanks. It is evident that the large surface of the table admits of the perfect separation of two or more different minerals from each other as well as from the tailings. The adjustable zinc slides on the delivery launder permit of an accurate division of the products being made at any moment.

The adjustments of the table are extremely simple. The speed is varied by means of a step-driving pulley. The stroke of the eccentric can be altered to any length required, and the length of the eccentric rod, upon which depends the amount of the upward throw of the mineral, can be changed while the machine is running.

The transverse slope of the table is regulated by means of a hand-wheel, which works the very simple tilting gear shown on the illustration.

It will be noticed that the surface of the table, the springs supporting it, and the cross pieces on which the latter rest, form one self-contained frame which is bodily tilted.

The longitudinal slope of the table can also be adjusted by means of the screw bolts attached to the foundation frame.

Special provision has been made with regard to the water feed. The feed-water trough extends the whole length of the upper side of the table, and in front of it is another trough of less depth divided into several sections and provided with numerous overflow spouts. The amount of water flowing from each section is regulated by valves, thus allowing of more or less water being used, as required, on different parts of the surface. The object of using open spouts instead of the usual pipes is that they cannot get so easily jammed if dirty water is used.

The surface of the table is covered with linoleum, and can either be provided with riffles, or used quite plain as may be desired to suit the ore under treatment.

The speed at which the machine is to be run will vary according to the class of ore from 240 to 400 revolutions per minute.

The slimes are fed into a distributer fixed to one corner of the table as shown.

The distributer has a perforated bottom, and as it vibrates with

the table it discharges the pulp evenly upon it. The pulp or slimes then flow in an even stream slowly down the table, and the separation immediately commences. The light tailings flow across the table into the waste launder, and the mineral is first of all classified into layers according to their specific gravity, and as these layers progress along the table the heavier parts, receiving a larger momentum, travel faster than the lighter ones; thus being separated according to their specific gravity they form distinct streaks, and, coming under the influence of the wash water flowing across the table, are washed off into separate launders.

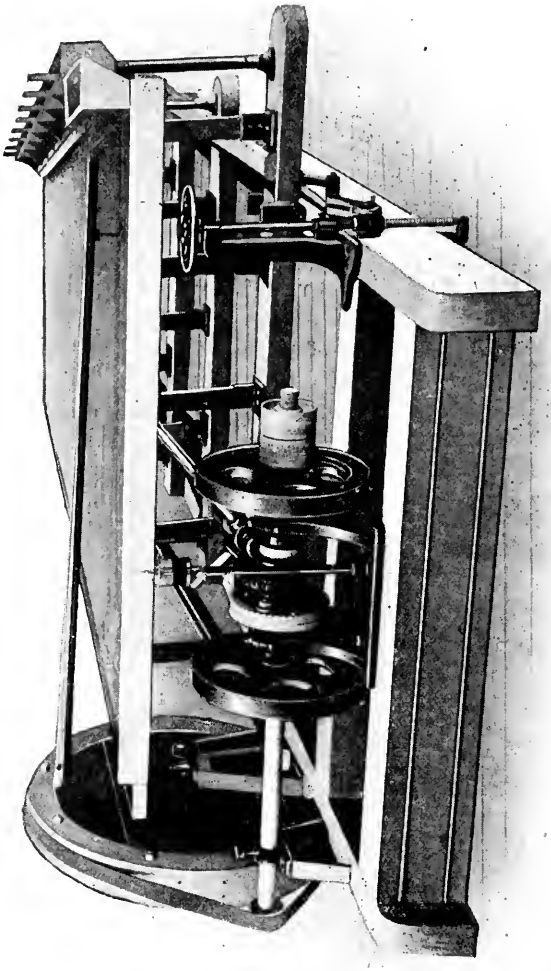


FIG. 243.—BUSS'S PATENT LÜHRIG VANNING TABLE. DRIVING GEAR.

These launders are provided with sliding trays, which allow the cutting out and separate discharge of such portions of the products as it may be desired to keep separate.

The proper inclination of the table will be found very quickly, and once it has been adjusted, which can be done during the running, it remains unvaried unless the class of ore changes.

The other points to be attended to are the "stroke" and the "throw." The stroke is adjusted by means of the eccentric, which is specially arranged for that purpose; whilst the throw is regulated by shortening or lengthening the eccentric rod by means of a hand-wheel.

The stroke, together with the throw or upward lift of the mineral on the table, and the speed, are the points which principally control the efficiency of the machine and also its capacity.

The "stroke" being its horizontal movement, is regulated by the eccentric, and the "throw" its upward movement, is controlled by the more or less upward position of the springs, it is evident that by a

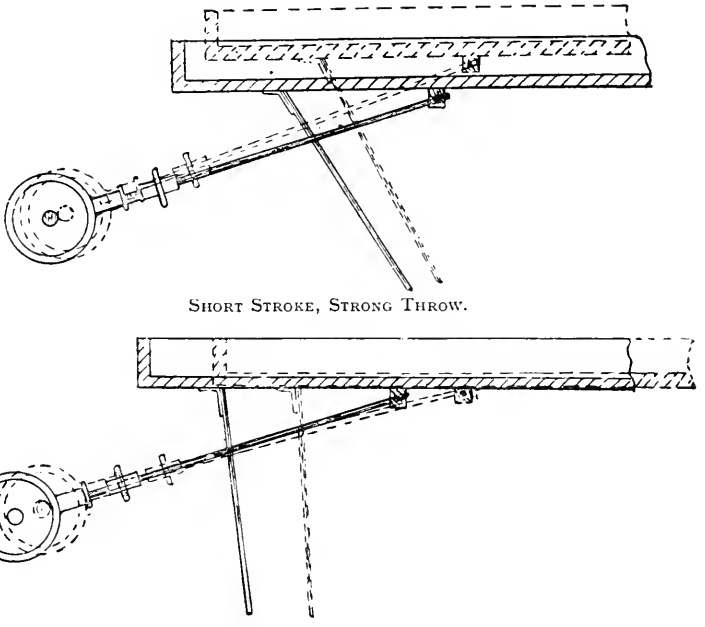


Fig. 244.—Long Stroke, Slight Throw.

variation in the adjustment of these two movements the action of the table can be regulated to suit any combination of mineral under treatment. These adjustments are illustrated in fig. 244.

It is evident from the foregoing observations that the construction of this machine is extremely simple, while it can easily be adjusted and worked even by unskilled labour.

The quantity which a single machine will treat is as much as 15 to 35 tons per 24 hours, but this naturally varies with the character and size of the mineral. Classification of the pulp is not absolutely necessary, as the table will treat with great efficiency ore varying greatly in size, but its most economical work is done, as in all concentrating machinery,

if due attention has been paid to preliminary sizing of the slimes. The table is able to treat much coarser material than can be worked on belt vanners.

I have several times seen this table in operation, and have experimented with it on a large variety of ores always with satisfactory results. Several of these tables are now in successful work, of which a description will be found on page 364, at a tin mine in Devonshire.

Tin Concentration in Cornwall.—The means employed for concentrating tin ore in Cornwall are, as a rule, of the most primitive description, consisting of various forms of flat and round buddles. The great loss in slimes, which amounts to about 50 per cent., has, however, recently brought about the introduction of improved machinery by some of the companies. It is estimated that in 1890 the mines within one mile of Carn Brea threw away £69,206 worth of tin, in addition to that carried to the sea.* The following tabular statement of the Government returns from mines, whose waste waters flow into the Portreath river, show accurately the amount of tin produced by concentration at the mines, and the amount of loss by imperfect concentrating appliances, but recovered by the stream tin workers in the river:

Mine.	1890.			1891.		
	Tons.	Cwts.	£	Tons.	Cwts.	£
Wheal Basset . . .	396	—	22,203	402	—	22,448
West Basset . . .	310	2	16,471	283	12	14,421
Wheal Uny . . .	141	6	7,982	177	10	9,648
Wheal Agar . . .	261	5	13,287	339	17	17,149
Penandrea	139	—	7,802	76	2	4,334
Totals	1247	13	67,745	1279	1	68,000
	Price per ton, £54 6 6			Price per ton, £53 3 3		
	Tons.	Cwts.	£	Tons.	Cwts.	£
Sold by streamers from Portreath river	428	—	17,126	330	6	10,469
	Price per ton, £40			Price per ton, £31 14 6		

Percentage of river to mine tin, in quantity, 33; in value, 25.

Doubtless the same waste goes on at other mines, so that we cannot

* "Transactions of the Mining Institute of Cornwall," Vol. IV. Part I. "Paper on the Treatment of Slime Tin," by J. Hicks.

doubt but that if improved concentration machinery were erected, many mines which now struggle along, or are worked at a loss, would then be worked to a profit, by the money which now goes into the pockets of the stream tin workers being turned into those of the mine shareholders without extra cost to themselves.

This question of improved concentrators is becoming all the more urgent from the fact that in depth the tin ore is not found in comparatively large crystals in the gangue, but is more and more finely disseminated through it as depth is reached.

The result of this is that the ores must be crushed finer. As a matter of fact, the mesh of the sieves employed in the stamp batteries has increased in fineness during the last fifteen years, from Nos. 30 and 32 B.W.G. to Nos. 35 and 36. The finer crushing entails the production of a larger percentage of slimes, and, unless improvements are made, the loss of slimes now estimated at from 50 to 80 per cent. will become still greater.

I hesitate to advice the adoption of any particular machine, but from the description of the Linkenbach table, the Frue vanner, the Embrey concentrator, and the Lührig percussion table already given, those interested in tin dressing will, I think, be able to choose for themselves the machine best adapted to their particular ore.

During the last ten years improved dressing machinery has been introduced into Cornwall, and I am indebted to my stepson, Mr. M. S. Stutchbury, for the following notes on "tin-dressing" or concentration:

"Metallic tin is almost exclusively obtained from the oxide, cassiterite or tin stone, which mineral is found in the granitic rocks underlying the clay slates of the Laurentian system, and, indeed, not infrequently in these clay slates themselves.

"Unlike many metals, it occurs in very finely divided particles, and we are thus at once confronted with difficulties in the concentration thereof.

"Black-tin, the miner's name for the concentrated tin stone, is worth at the present price of metal about £70 per ton, varying of course on the state to which the concentration has been carried. The theoretical percentage of tin in the oxide being 78 per cent., the ore is usually concentrated up to from 65 to 68 per cent. of metal per ton, the value of this is roughly 9*d.* per lb.; so it is obvious that nothing like the margin which is allowable for waste in washing in the concentration of lead and blende ores can be permitted in this case. In order, therefore, to extract all the tin stone, it has to be very finely crushed down, the ore being made to pass through anything from a 35- to a 70-mesh screen before any attempt is made at concentration. This crushing is invariably done with Californian stamps, and although at the present moment there are in Cornwall several hundred head of Cornish stamps in use, they

will doubtless soon be replaced by more modern machinery. After stamping, the slime is led over a series of vanners,—the products from 5 stamps being treated by one vanner,—here the waste gangue is largely extracted, and the resulting concentrate being either tin and mundic, supposing the ore contains mundic or else tin alone. Supposing it to contain mundic it is necessary to remove it, as it entirely spoils the value of the tin stone. As these two metals are of practically the same specific gravity, they cannot be separated by hydraulic means without resort being made to calcination which drives off the sulphur from the iron, leaving the oxide, then having the two oxides of tin and iron, it is possible to separate them hydraulically owing to the difference in their specific gravities.

"Owing to the finely divided state of the tin stone the ordinary rotary cylindrical calciner is not used, but that known as 'Brunton's Calciner' is generally employed.

"This calciner consists of a circular table built up of fire-brick supported on iron arms. It makes about 1 to 1¼ revolutions per minute, depending upon its diameter, which is usually about 18 ft. The finely powdered ore is distributed from the centre, and by means of arms on the table the ore is gradually made to work its way to the bottom, where it is swept off and collected. The sulphur from the mundic is led up a long flue where it deposits and can be collected, and before the fumes are finally allowed to escape into the air they pass through a spray of water which dissolves out the soluble gases.

"The product left to deal with from the calciner consists of the oxides of tin and iron. These are easily separated either on vanners or buddles.

"The Cornish tin-dressers say that it is not feasible to thoroughly clean the tin without dollying it. This they therefore do and presumably it pays them, although it is almost an impossibility for any one to obtain figures to compare the assay value before and after dollying."

The Clitters Tin Concentration Mill.—At the end of 1901 I had an opportunity of thoroughly inspecting this mill, which was then just completed, and which presents the most modern development of machinery for the dressing of tin ores. The operations at the mine are conducted under the superintendence of Mr. F. Dietzsch, A.R.S.M., M.I.M.M., the consulting engineer (and also a director) of the company.

The general arrangement of the surface plant and mill were devised by Mr. Dietzsch, jointly with Dr. J. Buss, M.I.M.M., who also designed the mill, and superintended its erection as engineer of the Lührig Coal and Ore Dressing Appliances, Limited, the latter supplying the complete dressing machinery. These two gentlemen are to be heartily congratulated on the success of their operations, a success which, in spite of the well-known prejudice of Cornishmen to modern methods of mining,

was acknowledged in our presence by distinguished Cornish engineers to be complete.

The mine and mill are situated close to the village of Gunnislake, in Cornwall, some four miles from the town of Tavistock, in Devon. Gunnislake is at the head of the navigable waters of the River Tamar, while on the opposite side of the river to the Clitters United Mines, Limited, are the chimneys and works of the famous Devon Great Consols. The mine is worked by adits, and we are informed that there are large reserves of rich tin ore in reserve above the adit waiting for the milling operations, which have now commenced.

The ore from the various adits is trammed to the foot of an incline, up which the waggons are hauled to the level of the ore bins by means of a small steam hoisting engine built by Messrs. R. Schram & Co. Water for milling operations is pumped up from the river to a reservoir above the mill, and the waste water after settling is also pumped back and used over again. The water used for condensing purposes with the mill engine is also mixed with the mill water, which is thus always kept at a temperature above freezing-point. The waste water flowing from the mill, after further settling in order to free it as far as possible from mud, is led away in a series of launders and subjected to a process of filtration before being finally allowed to rejoin the river. Every care is thus taken to avoid damage to riparian or other owners, and the admiralty need be in no dread that Plymouth harbour will be silted up from the Clitters United Mines, Limited. In the meantime we have left the ore waggons standing at the summit of the incline, ready to be tipped over the grizzlies shown at G in the accompanying plan and section (see Plate VIII.).

Referring to the plan and section it will be observed that the plant is divided into three separate systems. The first system is for the treatment of tin ores only ; the second system for the concentration and treatment of wolfram ores, containing some tin ; and the third system for the treatment of the calcined tin concentrates.

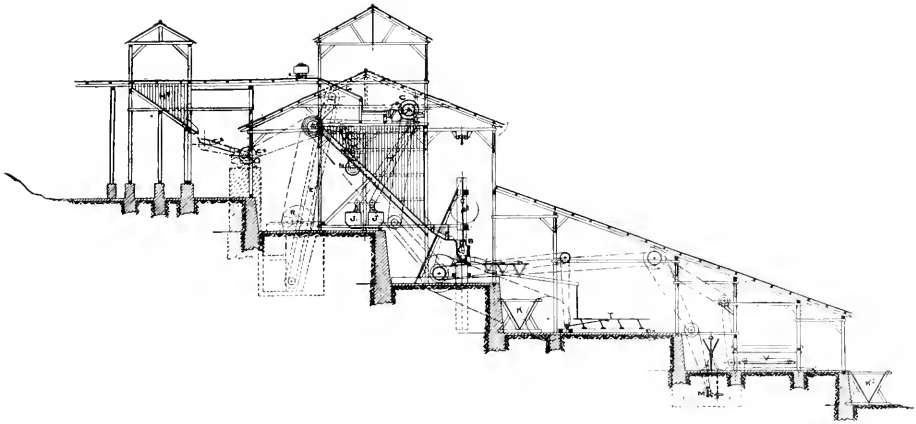
System for Tin Ores.—The tin ores which are hauled up an incline are dumped on to the grizzlies (G), the fines falling into the large storage hopper (H), whilst the large pieces are delivered on to platform (P) and fall on to the stone-breaker (C), where they are reduced to pulp metal size, falling into hopper (H). From here the broken ores and the fines are discharged automatically on to suspended Challenge feeders (F), which feed the stamp batteries (B). The latter are of the latest Californian type, and consists of 20 heads arranged in sets of 5 stamps each, each working independently. The pulp from the whole of the 20 stamps flows into the shoot (D), and is taken from here on to a series of spitzlutten (L), worked with an underwater current. The coarse sands are here graded and each size discharged separately on to buss swinging tables (T), each of which receives the sands from one spitzlutten. The fine pulp overflows the last

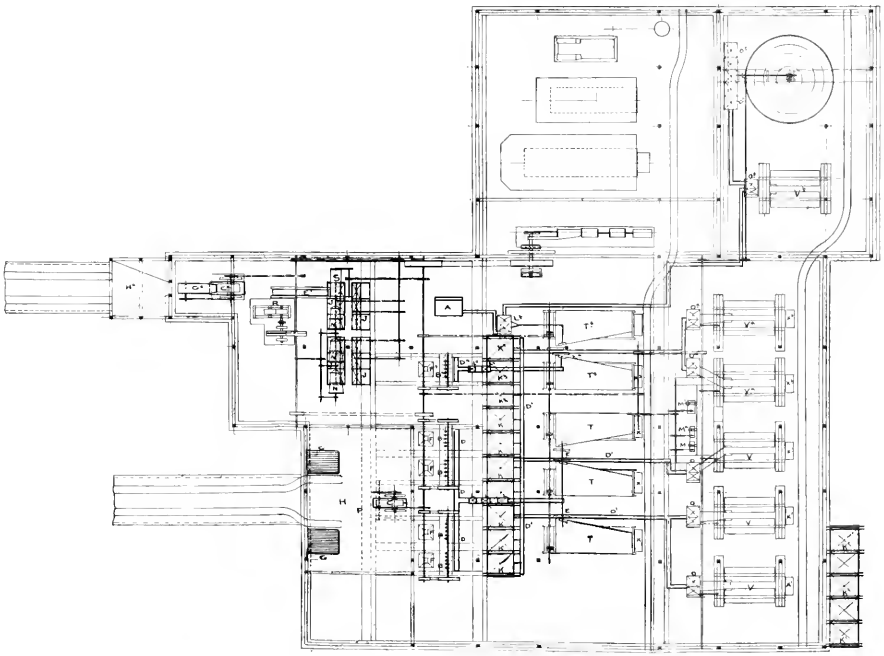
spitzlutten, and is discharged into the large spitzkasten (K), here the fine pulp is condensed and also classified at the same time. The condensed pulp is now discharged from the point of the spitzkasten through sluice valves into the shoots (Dl), being delivered from here into distributing boxes (O). The latter feed the Lührig vanners (V). The concentrates from the buss tables are automatically discharged into boxes (X), whilst the middlings are returned to elevator wheels (E), the tailings flow through a shoot into the settling spitzkasten (Kl) outside the plant. The concentrates from the vanners (V) are also automatically discharged into concentrate boxes (Xl), whilst all the middlings from the vanners flow to the middlings pump (M) which returns them for retreatment into the spitzkasten (K). The tailings from these vanners also go, together with the tailings from the tables, into the settling spitzkasten (Kl). The latter clears the water which flows to the pump (Ml), and is returned for re-use to the stamps. The tailings are discharged through valves from the point of spitzkasten (Kl), and flow from here to settling tanks, where the water is finally cleared before being allowed to flow into the river. The concentrates from the tables and vanners are taken on small trucks running on rails to the calcining house, which is situated close to the plant.

Wolfram Ore System.—The wolfram ores being partly very coarsely crystallised, it was found advisable to jig part of the ore in order to eliminate the coarse wolfram. The wolfram ores in this system are dumped into the hopper (Ha), pass from here on to the shaker (Ga), which feeds the larger sizes on to the stone-breaker (Ca). The shaker having a perforated bottom, the fines fall straight on to the crushing rolls (R), which also receive the broken material from the stone-breaker. The ore crushed into the rolls now falls into an elevator pit, and is raised from here by the elevator (El), being discharged from here on to the vibro-screen (S), which preliminarily sizes the material, and also allows the training of the fine pulp. The coarser sizes now go both for further sizing to the trommels (N), each size falling separately from here on to the four jigs (J). The jig concentrates are discharged into product boxes in front of the jigs, whilst the middlings from these jigs are fed on the Challenge feeder (Fa), which supplies the 5-head stamps (Ba). The pulp from these stamps flows through shoot (Da) over the spitzlutten (La). The latter feed the table (Ta), whilst the overflow from the spitzlutten flows into the spitzkasten (Ka), where it is condensed and flows through the shoot on to the distributing boxes (Oa), which feed the vanners (Va). The concentrates from the table (Ta) are discharged into a product box (Xa); whilst the middlings are returned by means of an elevator wheel (Ga), the tailings joining the tailings from the tin plant. The concentrates of the vanners are also discharged into boxes (Xb), whilst the middlings are returned by means of the pump (Ma) to the spitzkasten (Ka). The tailings join the tailings from the tin plant. The fine concentrates from

ng Appliances, Limited.*

[*To face page* 366.





Figs. 245, 246.—The Clitters Tin Concentration Mill, erected by the Lühric Coal and Ore Dressing Appliances, Limited *

* From the *Mining Journal*, Dec. 7th, 1901

[*To face page* 386.

the wolfram plant, when containing tin, have to undergo a separate treatment from the pure tin concentrates.

System for Calcined Tin Ores.—The tin concentrates after calcination are brought to the feeder (A), which feeds them regularly on to the spitzlutten (Lb). The coarser part of the pulp is discharged on to the table (Tb), whilst the finer pulp flows to the condensing boxes (ob). The latter supply the vanners (vb), whilst the overflow from these boxes, containing very fine material, goes on to condensing boxes (oc) which feed the turning table (Y). The concentrates from this system are now marketable products and are taken to the store-house, whilst the middlings are automatically returned into the system. It is intended to disintegrate any resulting coarse sands and to treat them simultaneously with other calcinal material.

Motive Power.—The motive power is supplied by compound condensing engine, and the steam by a Lancashire boiler. All the three systems are worked from one main shaft, and each can be used independently of the other. The mill is lit up with the electric light, and is so arranged that supervision is easy; while owing to the automatic nature of the arrangement the number of hands required is reduced to a minimum. The results already obtained on tin dressing are surprising, as the tables enrich the ore up to 1200 lb. of black tin per ton of concentrates, which is from four to five times better than any results formerly obtained by round buddles, while the automatic machinery reduces the cost of dressing to a fraction of what it is in mills of the old-fashioned type.

I have already described on page 357 the Buss table, and this machine has undoubtedly been a great success not only at this mine for tin dressing, but also at the Greenside Mines, in Cumberland, where the ore consists of galena, blende, barytes, and gangue.

Experiments are also being made to separate the Wolfram from the tin by means of a magnetic separator.

CHAPTER XIX.

THE MILLING OF GOLD ORES.

Mill for Treating Free Gold—Description of Mill—Cost of Milling—Test for Free Milling and Refractory Ores—Treatment of Concentrates—Mill with Concentrators for Refractory Gold Ores—Specification of 10-Stamp Mill—Power Required—Materials Required for One Month's Run—Cleaning the Plates.

Mills for Treating Gold Ores.—The ores of gold may be divided roughly into two classes: (*a*) Those in which the gold is in a free or metallic state, or partly so; (*b*) those in which the gold is associated with the compounds of other metals—usually the sulphides.

In the former case the milling of the gold ores is a very simple matter, and consists principally in reducing the ore to a state of pulp or slimes, by means of a stamp battery, or other pulverising machine, and then passing the pulp over a series of copper plates coated with mercury, or, as it is termed, amalgamated. The particles of gold attach themselves to the silvered surface of the plates in the form of amalgam, which is scraped off from time to time and put into a retort. The mercury is driven off by means of heat, and condensed for future use, while the gold is left in the form of a brown deposit ready to be melted into bars.

Simple as the process seems, it is surrounded with technical difficulties in connection with the pulverising and amalgamation, a few of the principal of which will be briefly pointed out. A full description, however, would require a special treatise, and the reader is referred to that of Mr. Eissler upon the subject.*

The general arrangement of a mill for treating free gold ores is shown in the section (fig. 247). The ore from the mine arrives by means of the tramway (*a*) which takes it, if possible, direct to the level of the top of the mill. If this is impossible, owing to the configuration of the land, then the ores must be hoisted by mechanical means. It is then tipped over the grizzly or inclined screen of iron bars (*b*), the rough ore being fed into the stone-breaker (*c*), while the fine passes through the screen direct into the hopper (*d*) and joins that crushed by the machine.

* "The Metallurgy of Gold," by M. Eissler. Fifth Edition. London: Crosby Lockwood & Son.

At the mouth of the hopper or magazine an automatic feeder (*e*) is fixed (see also figs. 151, 152, p. 232), and this regulates the supply of the ore to the stamp battery (*f*). The ore, after pulverisation, flows in the form of pulp or slimes through the screens in front of the stamps, and is spread in a thin sheet over the amalgamated plates (*g*). The free gold is caught and retained by the mercury, while the sand and water are conveyed out of the mill. The amalgamated plates are of the same width as the mortar box, and from 6 ft. to 12 ft. long, the usual length being about 8 ft. One or more amalgamated copper plates are also fixed inside the mortar box, and small quantities of mercury are occasionally dropped into the mortar while the stamps are running. The free gold is thus caught both inside and outside of the battery, and as it accumulates in the form of amalgam it is scraped off and retorted.

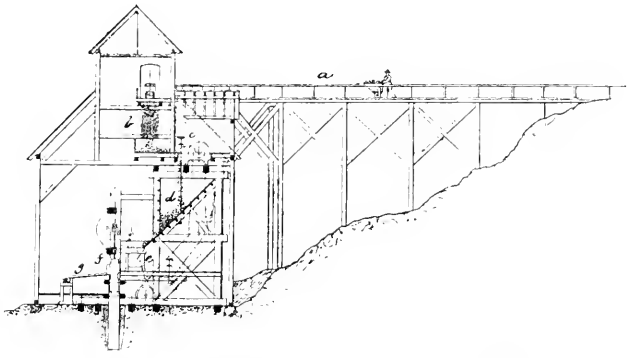


FIG. 247.—GENERAL ARRANGEMENT OF A GOLD MILL.

The stamps are usually fixed in one long row, so that the illustration will equally apply to a battery of 10 or 100 stamps.

When Huntington mills, or other special forms of pulverisers are used, they are fixed in the same position as that occupied by the stamps, and are followed by amalgamated plates. The motive power may be either steam, water, or electricity, and is applied to the main driving shaft (*h*).

This process of milling is one of the cheapest possible, and in large mills will not cost more than 16*s*., or say 60 cents per ton of ore; so that ore of a value of 16*s*., or say, $4 can be mined and milled to a profit, while under exceptionally favourable circumstances, with water-power and large masses of ore, a profit can be made out of mineral worth only 4*s*. per ton.

There are, however, but very few cases in which the ore is sufficiently free as to permit of its successful treatment by amalgamation only. It is usually allied with other minerals in the form of sulphides, such as those of iron, copper, lead, and zinc, as well as with the tellurides,

selenides, and antimonides of the metals; so that the gold, or a large portion of it, is so locked up with these impurities as to be unattackable by the mercury on the plates, and passes away with the sulphides. In some cases the loss of gold which thus occurs is not sufficient to cover the cost of concentration; but wherever the sulphides contain a payable amount of gold, it is necessary to put up a complete set of fine concentration machinery. As a certain proportion of the gold is usually in a free state, the whole of the ore must, as a preliminary, be reduced to the state of slimes, in order that it may be passed over amalgamated plates; and, as a consequence, the concentration machinery must be such as is adapted to the treatment of slimes.

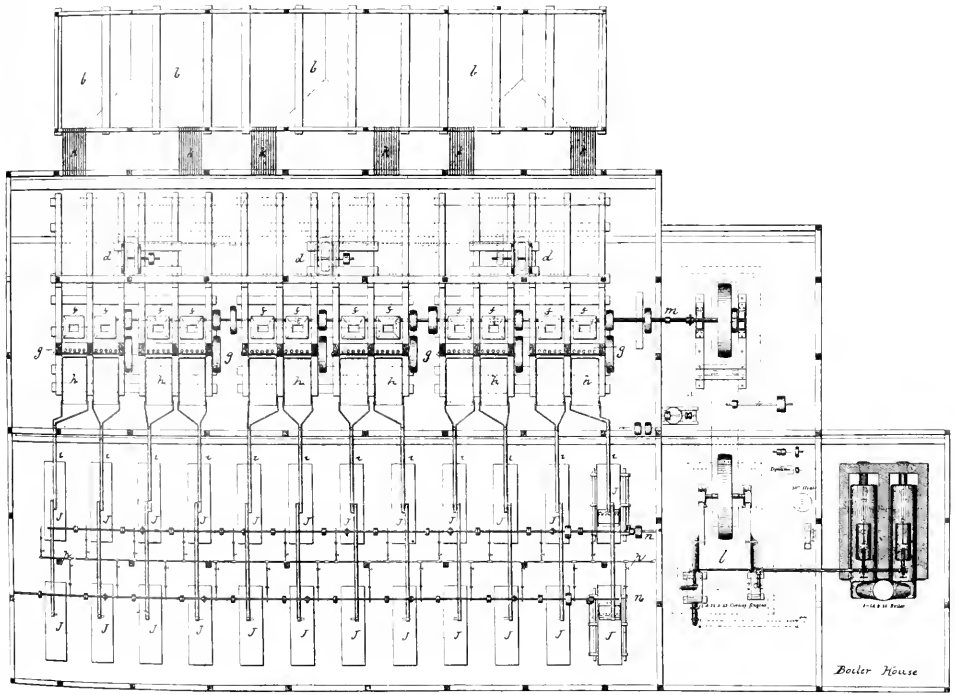
A rough idea as to the proportion of free gold in a sample of ore may be obtained by reducing it to powder in a clean pestle and mortar, and then concentrating it by panning. If the concentrates are now rubbed with mercury the free gold will be extracted, and the amount of gold in the residue may be found by assay. It often happens that lodes, or reefs, carry gold in the free state on, or near, the surface, and as a depth is gained the character of the ore gradually changes, and the sulphides, which near the surface had become decomposed, now predominate, necessitating the addition of concentrating machinery to the mill, so that samples taken from the outcrops of the reef, or even from shallow workings, must not be regarded as definitely proving that the gold is free. In erecting a new mill, on the supposition that the gold exists in a free state, it is advisable to arrange for the future addition of concentrating machinery; and if Frue vanners are to be employed, it is usual to estimate for two of these for each 5 head of stamps, or for each Huntington mill.

The extra cost of concentration, once the machinery is erected, is not great, nor do the machines absorb much power, as will be seen from the separate descriptions given of those usually employed.

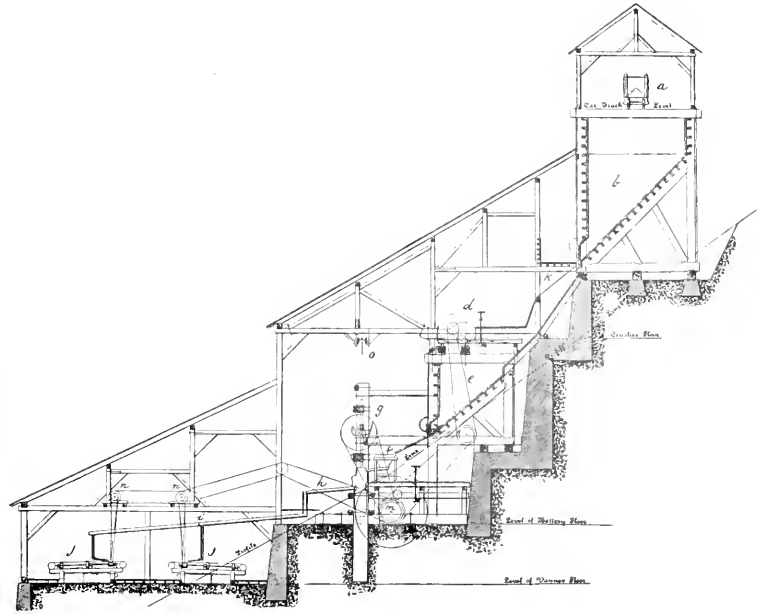
The concentrates obtained may either be sold as such, or undergo the further processes of roasting and chlorination, or treatment by the cyanide method, for the purpose of obtaining the gold in a metallic state, on the mine itself, according to the local facilities.

Most of the ores of gold contain a certain amount of silver which, in the case of free milling ores, is recovered with the gold in the concentrations, and can be extracted equally well, either by melting or pan amalgamation, or by some modifications and additions to the chlorination process. Where the amount of silver is considerable the ore should be classed as silver milling and be treated as such, as described on page 379.

Gold Mill with Concentrators.—The general arrangement of a gold mill with concentrating machines is shown in figs. 248 and 249 (Plate



PLAN.



SECTION.

Figs. 248, 249.—Sixty-stamp Gold Mill with Concentrators.

[To face page 370.

IX)., which are a plan and cross-section of the 60-stamp combination gold mill, with copper amalgamating plates and Frue vanner, as erected by Messrs. Fraser & Chalmers for the Montana Company, Limited.

The ore enters the mill by a tramway at (*a*), and is emptied first into the hopper (*b*) above the stone-breakers, which form reserves of ore, should there be any hitch in the delivery of the ore to the mill. From these bins the ore slides over inclined screens, or grizzlies (*k*), the fine stuff passing direct into the lower bins (*e*), while the coarse is crushed in the stone-breakers (*d*) of which there are three, and then also falls into the bins (*e*). The 12 automatic feeders (*f f*) regulate the supply of ore from the bins to the line of 60 stamps (*g g*) arranged in sets of 5 heads each, and then, in the state of pulp, sweeps over the amalgamated copper plates (*h h*) which takes up the free gold. The slimes containing the auriferous sulphides are carried by means of the troughs (*i i*) to the 24 Frue vanners (J J) where they are concentrated. The action of these vanners is described on page 322.

The mill is driven by an improved compound Corliss engine (*l*) having cylinders 14 in. and 24 × 42 in., receiving steam from two 54 in. × 16 ft. horizontal tubular boilers.

During the year 1888 this mill crushed 40,530 tons of ore at an average cost of $1·13, or say 4*s* 6½*d*. per ton, which price includes the wear and tear as well as all incidental expenses connected with the running of the mill and the working of the ore.

The main shafting (*m*) runs for the full length of the mill, and is connected by belting to each 10 heads of stamps, as well as to the counter-shafting (*n n*) from which the concentrating machinery is run.

An overhead travelling gear (*o*) is provided for the repairs to the line of the stamps.

A description of the working of the various machines referred to will be found in the paragraph relating to each special appliance.

Specifications for 10-Stamp Gold Mill for Working Free Milling Ore.

Breaker, Grizzly, and Feeders :—

1 Blake eccentric pattern improved crusher, 10 in. × 7 in., all complete.
1 grizzly, or ore screen, about 4 ft. × 10 ft., made from 2 in. × ¾ in. iron, with washers between to make opening about 2 in., rods to connect bars, with nuts for same.
2 Tulloch automatic feeders, complete, with wood frames and sheet iron hoppers.
All necessary track iron and wood screws for track for feeders to run upon.

Stamps :—

1 10-stamp mill of 850 lb., each stamp of improved design, arranged to run in one battery of 10 stamps, by belt and tightener from stamp countershaft.
2 high mortars or batteries, each about 5000 lb. weight, planed upon bottom and for screen frames, foundation bolt holes drilled by template, mortars arranged inside for receiving copper lining front and back.

2 hard wood screen frames, fitted to mortars.
4 wrought iron keys, for holding screen frames in place.
2 Russia iron slot punched screens, of such size as may be required.
10 patent stamp shoes, made from white iron, with soft grey iron necks.
10 dies, of best quality white iron.
10 heads, bored for stems and recessed for shoe stem.
10 stems, both ends tapered, made from best refined iron. Ends being tapered, when one end breaks the stem can be reversed and other ends used.
10 tappets with wrought gib and steel keys, all properly fitted to place.
10 cams (5 right and 5 left hand) fitted to cam shaft with steel keys, all properly marked to place, to give proper drop.
1 heavy hammered iron cam shaft, turned full length and key-seated for pulley and cams.
2 wrought collars and steel set screws, fitted to cam shaft.
3 heavy corner cam shaft boxes, babbitted and bored, planed upon back and furnished with bolts and caps.
2 jack shafts, not turned.
4 jack shaft boxes.
10 iron sockets for wood levers, lined with leather.
10 wood levers or finger pieces, for holding up stamps, fitted to sockets.
1 pair of double sleeve flanges for wood pulleys, turned and fitted together, with woodwork built up, hub key-seated, wood work turned up and painted, and securely bolted through flanges.
All bolts, rods, nuts, and washers, for 10-stamp framework complete, including all holding-down bolts and washers for mortars.
1 complete set of hard wood guide boxes, all worked out for stamp stems, with all guide bolts, nuts, and washers.
2 pieces of rubber packing, $\frac{1}{4}$ in. thick, for top of mortar blocks, for mortars to rest upon.

Water Pipes :—

1 complete set of water pipes for 10 stamps proper, with valves and fittings ready for connection with main supply ; also hose for washing copper plates in front of mill.

Copper :—

2 sheets of pure L. S. copper, 96 in. × width of mortar × $\frac{1}{8}$ in., for tables in front of mill.
2 sheets of pure L. S. copper, $\frac{5}{16}$ in., for mortars inside, all fitted.
2 sheets of pure L. S. copper, $\frac{5}{16}$ in., for mortars inside, all fitted.

Building Bolts :—

1 complete set of building bolts, rods, nuts, and washers, for frame of building, and also for ore bins.

Tighteners :—

1 stamp tightener for stamp belt, complete with wood frame, rack, pinion, hand-wheels, dogs, etc.
1 breaker tightener for breaker belts, complete, with swinging frame, chain, shaft, and hand-wheel.
1 main tightener for engine belt, complete, with wood frame, rack, pinion hand-wheel, dogs, etc.

Shafting, Pulleys, and Belting :—

1 main line turned shaft, $3\frac{3}{8}$ in. diameter × 11 ft. 3 in.
3 pillow blocks for $3\frac{3}{8}$ in. shaft.
1 pulley, 32 in. × 15 in., to drive stamps.
1 pulley, 42 in. × 14 in., on engine shaft, to drive main line shaft.
All necessary bolts for pillow blocks.
All necessary collars and set screws.
1 turned shaft, $2\frac{3}{8}$ in. × 8 ft. 6 in. for driving crusher.
2 pillow blocks, for $2\frac{3}{8}$ in. shaft.
1 pulley, 60 in. × 14 in., to receive power from engine.
1 ,, 36 in. × 10 in., to drive crusher countershaft.
1 ,, 24 in. × 10 in., on crusher countershaft.
1 ,, 40 in. × 8 in., to drive crusher.
All necessary bolts for pillow blocks.
All necessary collars and steel set screws.
1 rubber belt, 45 ft. × 14 in., 4-ply, for battery.
1 belt, 49 ft. × 14 in. × 4-ply, for engine.
1 ,, 70 ft. × 10 in. × 4-ply, for crusher countershaft.
1 ,, 47 ft. × 7 in. × 4-ply, for crusher.
1 ,, 27 ft. × 5 in. × 3-ply, for engine belt feed pump.
1 hide of lace leather.

Amalgam Safe :—

1 amalgam safe and strainer, with padlock.

Retort and Bullion Furnace :—

1 retort, complete, with cover, wedge, and condenser.
1 16-in. bullion furnace, with all ironwork, one set of crucible tongs, 2 gold bullion moulds, and one set of steel letters for stamping bullion.

Overhead Crawl and Block :—

1 overhead carriage crawl and track iron, with wood screws for same.
1 1-ton differential pulley block

POWER.

Engine :—

1 stationary slide valve steam engine, cylinder 9 in. bore × 14 in. stroke, complete, as per specifications attached. (This engine has power for driving the above described machinery only, together with 2 or 4 Frue vanners if required.)

Boiler :—

1 tubular steam boiler, 40 in. diameter × 10 ft. long, complete with all fixtures and trimmings, breeching and smoke stack.

Feed Pump, Heater, and Pipes :—

1 belt feed pump, 2 × 3.
1 heater, with pipe coil.
All pipes, valves, and fittings for steam, water, and exhaust to make power complete, plans of which are furnished by the manufacturers.
Total approximate weight, 60,000 lb.

Power Required for a 10-Stamp Wet-Crushing Gold Mill with Concentrators and Amalgamating Pan.

1 Blake rock breaker, No. 2	= 6	horse-power.
2 ore feeders	= 0	,,
10 stamps, 750 lb., 90 drops	= 12	,,
4 Frue vanner concentrators	= 2	,,
1 grinding pan, 3 ft. diameter	= 3	,,
1 settler	= 3	,,
Friction	= 4	,,
Total	= 30	,,

The above form of mill is capable of working 15 to 18 tons per day of 24 hours.

Estimates of Materials, Supplies, etc., Required for a 10-Stamp Gold Mill for One Month's Run.

Note.—Bracketed numbers refer to corresponding numbers below.

[1] 10 gall. lard oil, in $\frac{2}{3}$ shipping cases.
[2] 10 ,, cylinder oil, ,, ,,
[3] 50 ,, coal ,, ,, ,,
[4] 25 lb. tallow or compound.
[5] 6 boxes axle grease.
[6] 1 box candles.
[7] 50 lb. cotton waste.
[8] 10 lb. assorted packing for engine, valves, etc.
[9] 1 yd. $\frac{1}{16}$-in. sh. rubber for gaskets, etc.
[10] $\frac{1}{2}$ pint each of sulphuric and nitric acid.
[11] 5 lb. each cyanide of potassium and concentrated lye.
[12] 1 oz. metallic sodium.
[13] 4 oz. prepared amalgam.
[14] 3 flasks mercury (230 lb.).
[15] $\frac{1}{2}$ doz. whisk brooms.
[16] 1 fine sponge.
[17] 1 yd. 8 oz. cotton duck.
[18] 2 amalgam knives.
[19] 1 stone mortar and pestle.

Approximate cost, $270.00.

Remarks.

Note.—Bracketed numbers refer to corresponding numbers above.

[1] Lubricants of all kinds are generally wasted by ignorant of careless employés. We have allowed liberal quantity here.
[2] With care and proper oil cups, much less quantity is sufficient.
[3] Dependent on season and latitude and number of mill lanterns.
[4] For stone-crusher and shafting bearings.
[5] For cams applied properly, it gives a coating which thereafter needs a mere touch of grease.

[6] About 6 candles will be consumed per night. (Incandescent electric lights are cheaper than candles after first expense is incurred.)
[7] After rejected by engineer, should be washed and used on shafting and rock-breaker.
[8] Kind dependent on engine, quantity sufficient to repack, say once a month.
[9] Necessary for packing gaskets and screens, etc.
[10] Useful only to burn cast iron, copper, etc., from the residuum after clean-up, where gold or amalgam exists.
[11] See remarks further on.
[12] For cleaning mercury after retorting.
[13] Use on plates in first starting of a mill, if running continuously, thereafter not necessary.
[14] See remarks further on.
[15] See remarks further on.
[16] For taking sand, etc., from surface of amalgam and mercury.
[17] For squeezing amalgam.
[18] For use on plates.
[19] For grinding small lots of amalgam.

The above estimate is what should be ordered if it is required to run a 10-stamp mill in perfect condition for one month. (No lubricants to be expended for mine pumps or other machinery.) All mill supplies should be placed under lock and key, and employés forced to be strictly economical in their use, and, where necessary, instructed in the same. In ordering a six months' supply, multiply by six, and deduct 10 per cent. Should supplies fall short, there is a waste of material needing correction.

Cyanide of potassium is useful in coating the plates with mercury, or when, from the presence of arsenic, sulphur, etc., or heavy concentrates. the plates become discoloured or blackened. The indiscriminate use of above, or acids, is to be strongly condemned. Verdigris appears to be the *bête noire* of amalgamators, and the reasons for using acids and alkalies indiscriminately only serves to alter the nature of the copper plates; this never should be done. In case of a mill started for the first time, a small quantity of prepared amalgam, spread equally over the upper half of the plate, will be useful in excluding the air (oxygen) from the plates, and prevent verdigris (oxide of copper in this case) on ore running from say, $5 per ton and upwards. Every two or three days other things, such as the use of mercury feeding the batteries, and proper brushing, will be sufficient to conquer the verdigris. Whisk brooms are best to brush the plates; these brooms should be cut to one-half their usual length, so as to give a good stiff brush. The plate should be brushed hard over every inch of its surface, and the amalgam thoroughly loosened from the plate. Then commencing at the top of the plate, where the most amalgam will be formed, with stiff brushes the amalgam should be removed perpendicularly (not brushed to the centre) to the lower portion of the plate, where the surplus amalagam should be removed. This

leaves a thin coating of amalgam over the entire surface of the plate, excluding the air, and preventing verdigris. If plates are not run too wet (excess of mercury) this method will never fail to prevent oxidation. Acids and alkalies only serve to precipitate verdigris after a few days, or form salts of copper, which pop off only to return as an oxide, with tenfold power and quantity. In brushing the plates, a weak solution of cyanide of potassium (in case of heavy concentrates) and concentrated lye (weak) in case of grease on the plates may be used.

CHAPTER XX.

THE MILLING OF SILVER ORES.

Free Milling Ores—Roasting Milling Ores—Combination Process—Wet Crushing Silver Mill—Specification for 10-Stamp Mill—Power and Water Required—The Working of the Mill—Amalgamating Pans and Settlers—Blanket Tables—Sand Sluice—The Boss Continuous Process.

THE ores of silver, like those of gold, are divided, for milling purposes, into two general classes: (*a*) Free milling ores, or those which can be amalgamated direct after pulverisation; and (*b*) Roasting ores, which, before amalgamation, require a preliminary roasting. The free milling ores are crushed in a wet, and the roasting milling in a dry, state.

Free Milling Ores.—The minerals which contain the silver in such a form, that it can be brought into contact with, and amalgamated by, mercury, either with or without the aid of chemicals in the amalgamating pans, are those best suited for the free milling process, and are those which contain native silver, chloride of silver, and sulphide of silver in certain forms. On the other hand, those silver ores which are mixed with the sulphides of iron, copper, lead, zinc, and antimony, are not adapted to a free milling process, owing to the presence of the base metals interfering with the amalgamation, either by setting up chemical reactions of their own, and so fouling the mercury, or through their being combined with the silver in such a way that something more than the mechanical action of pulverisation is required to separate them.

The deposits, veins, or reefs of silver ores, like those of gold, are often free milling at or near the surface, where they have been subject to the decomposing action of the atmosphere, but gradually become refractory as depth is gained, so that the mineral obtained beyond a certain depth is no longer free milling, and must be roasted before it can be amalgamated. The line of demarcation between the two classes of ore is never very definite, so that it sometimes happens that a certain amount of loss must be put up with when the ore is in the transition state, and before it becomes entirely refractory, as the process of free milling is cheaper than that of roasting milling.

The decomposed silver ores just mentioned, together with occasional

natural deposits of chloride of silver, and still rarer ones of native silver, comprise those which can be advantageously treated by the free milling process.

The cost varies greatly, according to local conditions, price of labour, fuel, water, and materials, and also with the use of steam or water as a motive power, the limits being from 15*s.* to 40*s.* per ton of ore. The former price can only be reached by large mills having exceptional facilities, driven by water-power. The number of men employed in a 25-stamp mill, with 10 amalgamating pans, having a total capacity of from 50 to 55 tons of ore per 24 hours, would, in a well-managed mill, be 15, and the cost of labour would be from 6*s.* to 9*s.* per ton of ore, while the amount of silver saved would vary from 60 to 80 per cent. of the assay value of the ore. A wet crushing silver mill is described on page 379.

Roasting Milling Ores.—The number of ores which can be subjected to the free milling process are few, as compared with those which can be treated by the roasting milling operation which consists in roasting the ore in a suitable furnace with salt, previous to its amalgamation in pans, or treatment by the lixiviation or leaching process described on page 399. The roasting drives off the sulphur, and converts the silver into chloride of silver, in which state it can be amalgamated; it, however, entails loss of silver, especially when the ore contains arsenic or antimony; and this loss will vary according to the nature of the ore, and the type of furnace used, from 2 to 25 per cent. of its contents in silver. The amount of silver which can be recovered by amalgamation is estimated at from 90 to 95 per cent. of that contained in the ore after roasting, and the cost of the process, which necessitates dry stamping and heavier machinery, is from 32*s.* to 60*s.* per ton of ore.

In addition to the two processes of silver milling above mentioned, which are adapted to two distinctly different classes of ore, there is another which is more especially valuable for the treatment of many gold and silver ores, either when separate or combined, in which the amount of foreign sulphides is not sufficient in quantity to permit of the use of roasting, and is yet so great as to militate against the economical use of free milling.

The Combination Process to which we refer is especially adapted to this class of ore, and is, briefly, wet crushing followed by amalgamation over copper plates if free gold is present, then concentration by means of Frue vanners, or other fine concentrators, and finally the pan amalgamation of the tailings, either by settlement previous to amalgation, or by the Boss continuous process, described on page 389.

The result of this arrangement is that the free gold is caught on the plates, the refractory ores and sulphides are enriched and concentrated into a small bulk, and any value left in the tailings is recovered by the

pan amalgamation. The advantages claimed by the advocates of this process are:

1. The grinding in the pans is lessened or entirely dispensed with, and the wear and tear of castings is either decreased or done away with, and there is a consequent saving in fuel and motive power.

2. The loss of quicksilver is decreased.

3. Coarser crushing, and therefore increased capacity of the stamps is possible.

4. Bullion of a higher grade is obtained.

5. The total percentage recovered is increased, and varies from 75 to 85 per cent. of the silver in the ore.

The cost of the process is from 12*s.* to 40*s.* per ton, and in the case of the Montana Company, Limited, the adoption of this process resulted in a total saving of from 32*s.* to 40*s.* per ton over simple pan amalgamation, while the loss of mercury decreased by $\frac{3}{4}$ lb. per ton of ore, and the grade of the bullion rose from 500 fine up to 900 fine.

Silver Mill, Wet Crushing.—The general arrangements of a wet crushing silver mill will be seen in the section (fig. 250). The ore arrives from the mine by the tramway, at *a*, and is tipped down a chute to the level of the mouth of the stone-breaker (*b*).

The crushed ore is received in the bin (*c*), and is automatically fed into the stamps (*e*) by means of the feeder (*d*). The crushed pulp flows into the tanks (*ff*) where it settles, and the excess of water is drained off. The thick pulp is shovelled into the amalgamating pans (*g*) in regular charges, and is worked for several hours together with a mixture, first of salt and sulphate of copper and other chemicals, and finally with additions of quicksilver. A perspective view, showing two amalgamating pans (*g g*) and one settler (*h*) is given in fig. 257 (page 389).

When the operation of amalgamation is finished, the contents of the pans are run off into the settling tanks (*h*) in which the pulp is thinned down with water, and stirred gently so as to allow the quicksilver and amalgam to settle to the bottom, after which the slimes are run off, either to waste, or, as in some cases, are treated on fine concentrators, with a view to the recovery of any remaining value in them, as in the description of the Boss process on page 389. The amalgam which has settled to the bottom of the tanks (*h*) is drawn off and strained, in order to get rid of the excess of mercury, and is then retorted, and the resulting mass of gold and silver melted into bars into the furnace (*l*).

In the old mills the quicksilver was carried about by hand, to the points at which it was required. In the modern mills, however, it is hoisted by means of the elevator (*j*) to the collecting tank (*k*) from which it is conducted by pipes to the machines which use it.

It is reckoned that 5 stamps will crush sufficient ore to keep 3 pans

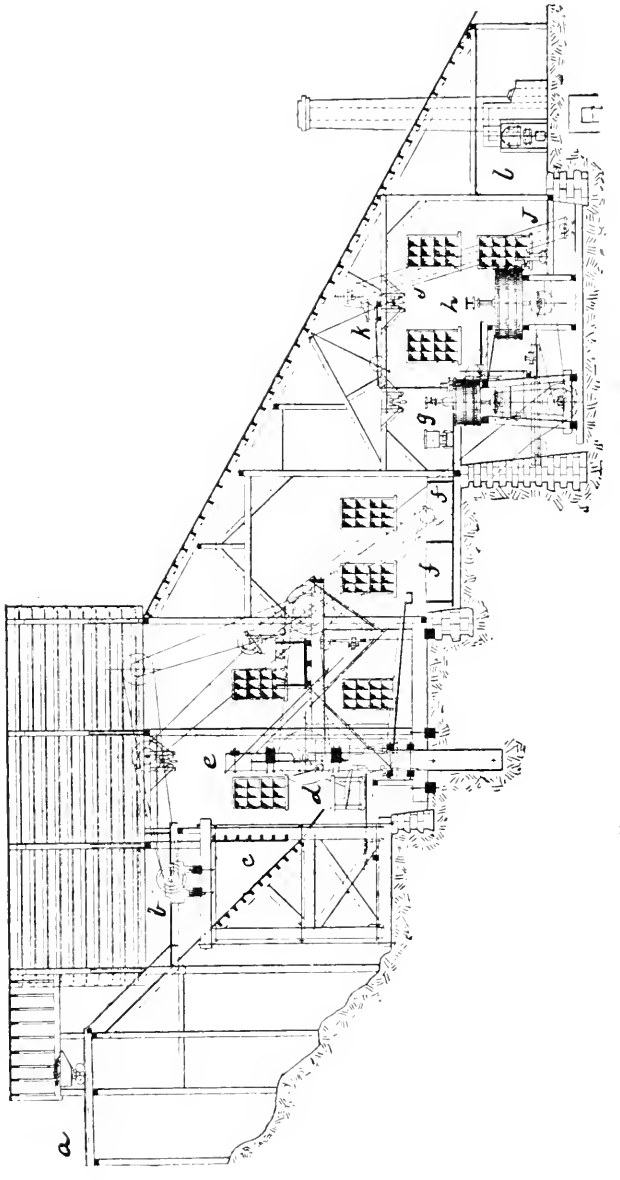


FIG. 250.—SECTION OF A WET CRUSHING SILVER MILL.

going, so that a 10-stamp mill, such as the one just described, would require 6 pans and 3 settlers, and also 1 clean-up pan, of which particulars will be found on pages 385–387.

The following is a complete specification of the machinery used in a mill such as that just described:

SPECIFICATIONS FOR 10-STAMP WET CRUSHING SILVER MILL.

Crusher:—

1 10 × 7 in. Blake crusher, to be furnished complete, ready to run when set in place.
1 duplicate set of jaw plates for above crusher.

Grizzly:—

1 Grizzly, or ore screen, for relieving breaker, size 4 × 10 ft. complete.

Automatic Feeders:—

2 Tulloch improved automatic feeders complete, with wood frames and sheet iron hoppers. All necessary track iron, punched and countersunk with wood screws for laying same for feeders to operate upon.

Stamps:—

1 10-stamp mill of improved design, each stamp weighing 850 lb., arranged to run in one battery of 10 stamps by belt and tightener from stamp countershafts, complete in detail as below.
2 high mortars or batteries, double discharge, all to be complete with screen frame and faces planed; also planed upon bottom for resting upon foundation. The bolt holes drilled by template.
4 hard wood screen frames fitted to mortars.
8 wrought iron keys for holding screen frames in place.
4 Russia iron slot punched screens, of such size as may be required.
10 patent stamp shoes, made from white iron, with soft grey iron necks.
10 stamp dies of best quality white iron.
10 stamp heads, bored for stems, and recessed for shoe stem.
10 stamp stems, made from extra fine iron, both ends tapered; when one end breaks the stem can be reversed and other end used.
10 stamp tappets, with wrought iron gib and steel keys all properly fitted to place Tappets faced on ends.
10 cams (5 right and 5 left hand) fitted to cam shaft, with steel keys all properly marked to place to give proper drop.
1 heavy hammered iron cam shaft, turned full length, key-seated for cams and driving pulley.
2 wrought iron collars with steel set screws, fitted to cam shaft.
3 heavy cam shaft boxes, babbitted, hammered, and bored, planed upon back, and furnished with bolts and caps.
2 jack shafts, not turned.
4 chairs, or sockets, for jack shafts to rest in.
10 iron sockets for wood levers, lined with leather, for stamp holders.
10 wood levers, or finger pieces, for holding up stamps, fitted to sockets.
1 pair of double sleeve flanges for wood pulley, turned and fitted together with woodwork built up between, hub key-seated, woodwork turned up and painted and securely bolted through flanges, to be fitted with steel key, properly marked to place.
All necessary bolts, rods, nuts, and washers for 10-stamp framework complete, including all holding down bolts and washers for mortars.

1 complete set of hard wood guide boxes, all worked out for stamp stems, with all guide bolts, nuts, and washers.
2 pieces of rubber packing, ¾ in. thick, for top of mortar blocks for mortars to rest upon.

Water Pipes :—

1 complete set of water pipes for 10-stamp mill, including all valves, water cocks, and fittings for supplying each stamp with water. Connection to be prepared to receive water from main supply. (The piping actually furnished does not include sufficient to connect with main supply.)

Combination Pans :—

4 improved combination amalgamating pans, each 5 ft. diameter, with wood staves, to be furnished with upright cone in bottom ; upright spindle fitted with separate steel toe ; 2 hand wheels and screw on top of spindle for raising Muller nut for screw ; driver sleeves ; driver arms separate from sleeves and bolted to same Muller plate ; 8 cast iron shoes and 8 cast iron dies to each pan ; wrought iron bands and lugs for staves ; step box fitted on plate, which also carries one bearing of countershaft ; step box fitted with steel buttons and bushings ; countershaft ; driving pulley ; out end bearing for shaft. All bolts for boxes for bolting to framework.

Settlers :—

2 8-ft. combination settlers complete, the same in detail as pans enumerated above, with the exception of shoes and dies. Wooden shoes to be furnished with settlers.

Clean-up Pan :—

1 48-in. clean-up pan, all complete as usually furnished, the same as pans detailed above.

Retort :—

1 12-in. silver retort, all complete, with cover bar and hand screw for holding cover in place ; carriers ; fire front complete, with fire door and liners, dead plate, back bearer, double grate bars, condensing pipe, cast iron ash pan ; all necessary wall binders and rods for bracing brickwork.
1 set of castings for 16-in. bullion furnace complete, including top cover bearing bars, grate bars, anchor bolts, etc.
6 assorted black lead crucibles and covers.
1 set of trays or cups for holding amalgam.
1 pair crucible tongs.
1 set of bullion moulds, three in number, assorted sizes.
1 set of steel numbers for stamping bullion bars.
1 iron floor plate, punched and countersunk, with wood screws for laying same for retort room floor.
1 smoke stack for retort bullion furnace. of suitable diameter and length, with base plate and guys for staying stack.

Quicksilver System :—

1 complete quicksilver elevator, with rubber belt, Russia iron cups, and all fixtures and fittings required for making elevator complete, including
1 upper and lower quicksilver tank.
2 quicksilver charging pots.
All pipes, iron cocks, and fittings for the complete quicksilver circulating system that may be required to make same complete.

Overhead Crawls :—

3 overhead carriage crawls complete.
2 2-ton differential pulley blocks.
1 1-ton differential pulley blocks.
All necessary track iron, punched and countersunk, with wood screws for laying same for overhead crawls to run upon.

Piping :—

All necessary water pipes, valves, and fittings for the complete mill, for supplying pans and settlers with the necessary steam and water, ready to receive connection with main supply.

Tighteners :—

1 crusher tightener complete.
4 pan tighteners complete.
1 stamp tightener complete.

Shafting, Pulleys, and Belting :—

All necessary shafting, pulleys, boxes, and belting for driving all of the above described machinery in accordance with our drawings
All the belting throughout the entire mill to be Boston Belting Company's best brand.
All pulleys to be turned, faced, and balanced ; pillow blocks to be planed upon bottom and lined with best babbitt metal and bored out ; couplings to be fitted to shaft with keys, to be turned and faced ; all bolts to be furnished for all bearings ; all key-seats to be cut in shafts so as not to be in bearings.

Building Bolts :—

All necessary bolts, rods, nuts, and washers for the complete framework of mill building in accordance with our drawings as usually furnished.

STEAM POWER.

Engine :—

1 Fraser & Chalmers' slide valve engine with Corliss style frame, size 14 × 23 in., all complete in detail.

Boilers :—

2 Fraser & Chalmers' tubular steam boilers, each 48-in. diameter × 14 ft. long, complete in detail.

Heater :—

1 24-in. tubular steam heater complete, including galvanised iron pipe for passing through roof.
1 No. 3 Knowles' steam boiler feed pump.
All necessary pipe connections for properly connecting engine, boiler, heater, and feed pump.

Total approximate weight, 175,000 *lb.*

The mill as covered by specifications is complete and automatic.

The power required for working the above 10-stamp wet crushing silver mill to a capacity of from 18 to 20 tons per 24 hours, would be :

1 Blake rock feeder, No. 2	6 horse-power.
2 ore feeders	0 ,,
10 stamps, 750 lb., 90 drops	12 ,,
6 grinding pans, 5 ft. diameter	30 ,,
3 settlers, 8 ft. diameter	9 ,,
Friction	7 ,,
Total	64 ,,

The water required for the whole mill will be 2200 gallons per hour.

The Working of a Wet Crushing Silver Mill.—It is not within the scope of the present volume to enter into full practical details of the various milling plants described; all that can be done is to give the general outlines of the working of the processes, and refer the reader to some of the numerous treatises which have been written on these

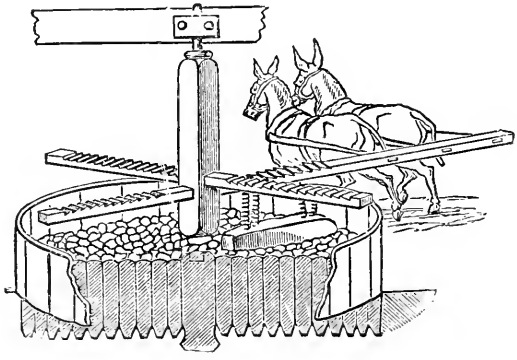


FIG. 251.—THE ARRASTRA.

subjects. For the details of silver milling my readers cannot do better than study Mr. Eissler's "Metallurgy of Silver," * which they will find full of practical information, and in more detail than in the following notes, for many of which I am indebted to the courtesy of Messrs. Fraser & Chalmers, Limited.

Crushing.—At the outset we come across a disputed point as to the crushing of silver ores. Formerly it was the universal system to crush coarse in the batteries, and then use the pans for the grinding of the ores, a system which entailed great wear and tear in the pans, a greater loss of quicksilver, and also a greater expenditure of power, while the fine grinding in the pans forced the quicksilver to saturate itself with

* "The Metallurgy of Silver," by M. Eissler. Fourth edition. London: Crosby Lockwood & Son.

foreign matter, and rendered it inert for the amalgamation of the gold and silver. The opposite method is to stamp fine in the batteries, and use the pans for amalgamation only, and not for reducing the ore still finer by grinding; and, strange as it may seem, it is very probable that better results can thus be obtained than by the former and more ancient method.

Amalgamation.—The modern amalgamating pan, such as is shown in figs. 252, 253, is the development of the old Spanish-American arrastra, of which, for the sake of comparison, an illustration is given in fig. 251. Some of the pans are provided with a false bottom, forming a steam chamber, as in fig. 271 (page 416), while in others the steam is introduced direct into the pulp, for the purpose of heating it, by means of a pipe. The pan holds from $1\frac{1}{2}$ to 2 tons of pulp according to its size, and water is mixed with it as it is shovelled in from the settling tanks, in such a quantity as will enable it to keep the finely

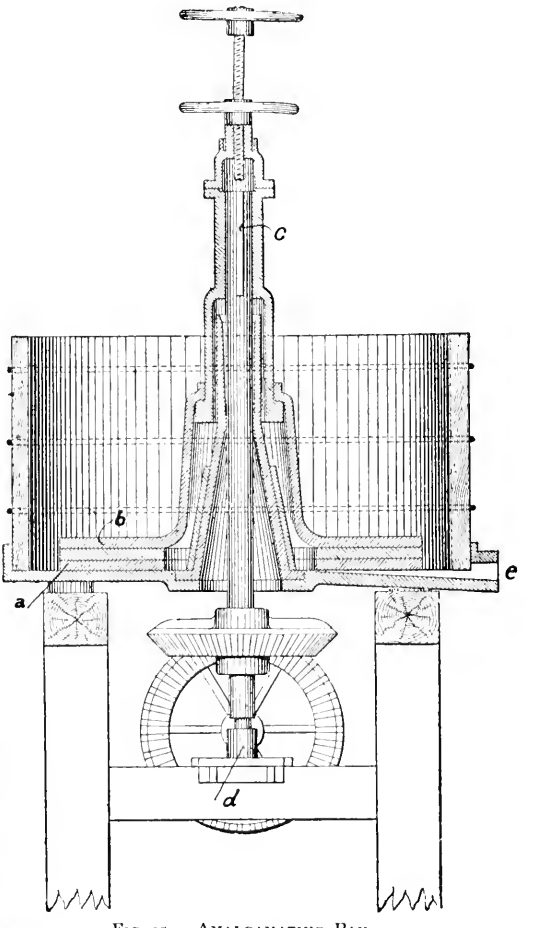


FIG. 252.—AMALGAMATING PAN.

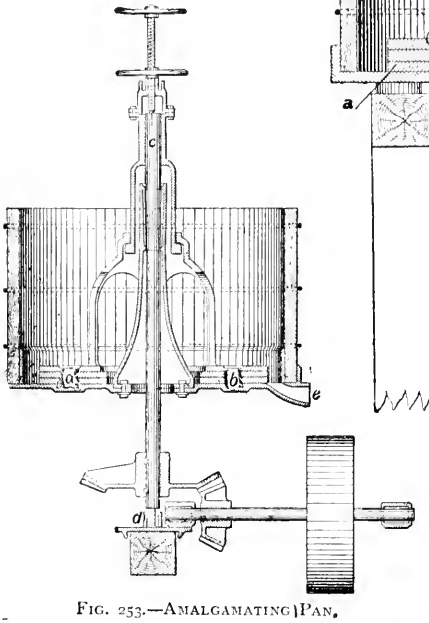


FIG. 253.—AMALGAMATING PAN.

divided globules of quicksilver in a state of suspension throughout its mass, and yet not so thick as to prevent its free circulation.

The heat should be kept at about 200° Fahr., and the muller, which at first does not touch the grinding surface, is gradually lowered, and allowed to grind either with its full weight or otherwise, according to the class of ore. In the course of two hours or so, the pulp is reduced to the required condition, and quicksilver is then scattered over the contents of the pan in the proportion of about 1 lb. per 20 lb. of ore, the muller being slightly raised so as to prevent the mercury from being too finely divided, the speed being from 60 to 70 revolutions per minute.

This is kept up for another two hours, during which time it is the

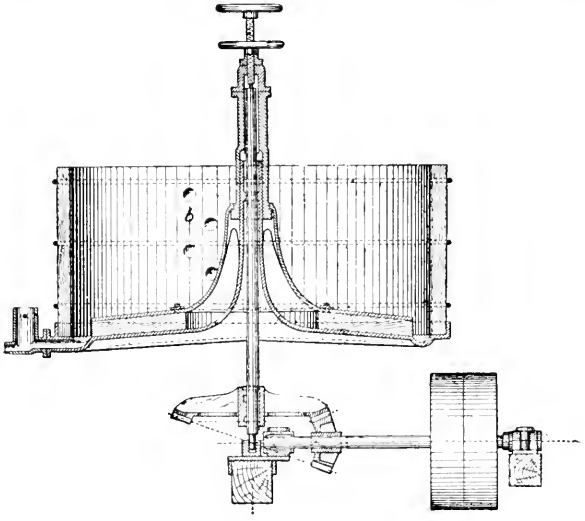


Fig. 254.—The Settler.

practice of most mill-men to add certain chemicals, with a view to assist the process of amalgamation. In former times most absurd decoctions were used for this purpose by mill-men, blindly ignorant of chemistry and chemical reactions; now, however, they are confined to two, viz., salt and sulphate of copper; and seeing that some mills use one, some the other, while others use none of either, it is just possible that neither is beneficial or essential to the different working of the ore in the pans. A more important point which is often neglected, which may involve the saving or loss of many dollars per day, is the pulp current, which must be uniform and regular in order to insure uniform work, and must be strong enough at the bottom of the pan to carry the mercury with it. The motion of the revolving muller makes a current by throwing the pulp to the outside as it advances, which then rolls up the side and is curved over by the wings, which are in the form of inverted

ploughshares, and is then thrown down to the centre again. The current above the muller is thus of necessity a good one, and it is desirable that the one underneath should be equally good.

From the amalgamating pans the pulp flows at the end of the operation into the settler placed immediately below. There are many varieties of settlers, but the general form is shown in fig. 254. The object of the settler is to keep the pulp in gentle motion, at the same time diluting it with water to such an extent that the heavier particles of quicksilver and amalgam will separate from the mass and fall to the bottom. With this object in view the two points to be regulated are the speed of the muller and the quantity of water used. If the speed is too great the quicksilver will be prevented from coming to rest on the bottom, if too slow then the sand will settle with it. If too much water is added the sand will not be kept in suspension, and will settle with the mercury, if too little is used then the pulp will be too thick for the mercury to separate from it.

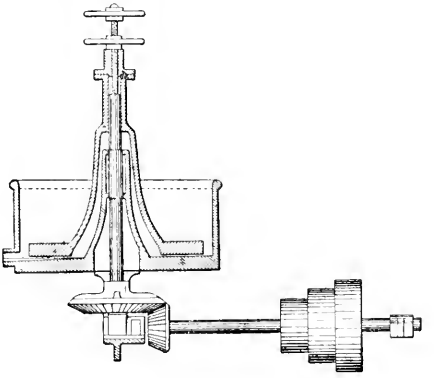


Fig. 255.—Clean-up Pan.

The quicksilver and amalgam from the settlers is run off at stated intervals and strained through a filter. The quicksilver is returned to the mill by means of the elevator, and the amalgam, if dirty and impure, is worked up with additional quicksilver in a clean-up pan, such as is shown in fig. 255 after which it is retorted in order to separate the gold and silver from the mercury. The bullion is melted in a wind furnace and cast into ingots ready for sale. The mercury driven off by the heat of the retort is condensed and is then ready for the mill again.

The mixture of sand, water, and various finely ground sulphides from the settler is sometimes allowed to run to waste; but when it contains ore of any value, it is usual to endeavour to concentrate it by some cheap means. For this purpose it may be treated in agitators which are a supplementary form of settler, or in any of the appliances used for fine concentration, provided that there is sufficient value in the ore to pay for the process.

The general arrangement of amalgamating pans and settlers in a mill is shown in fig. 257, in which *g g* are a pair of pans, and *h* is the settler; further details will be found on page 415.

Blanket tables and *sand sluices* are both very effectual. The former is a long shallow trough about 20 in. wide, with sides from 1 to 2 in. high,

and of an indefinite length, and may be as long as 300 ft., with a fall of from $\frac{1}{2}$ to 1 in. per foot. They are covered with coarse blankets cut into long strips, in the fibre of which the heavier grains of sulphides and particles of amalgam are retained. The blankets are taken up from time to time and washed in clean water, the stream of tailings being diverted in the meantime down a parallel line of blanket troughs. The concentrates thus obtained are worked up in pans, and usually realise from £4 to £6 per ton, thereby materially adding to the milling returns, and reducing the original cost of crushing and amalgamation. Blanket tables are shown below the plates in fig. 182 of Hornsby's battery (p. 270).

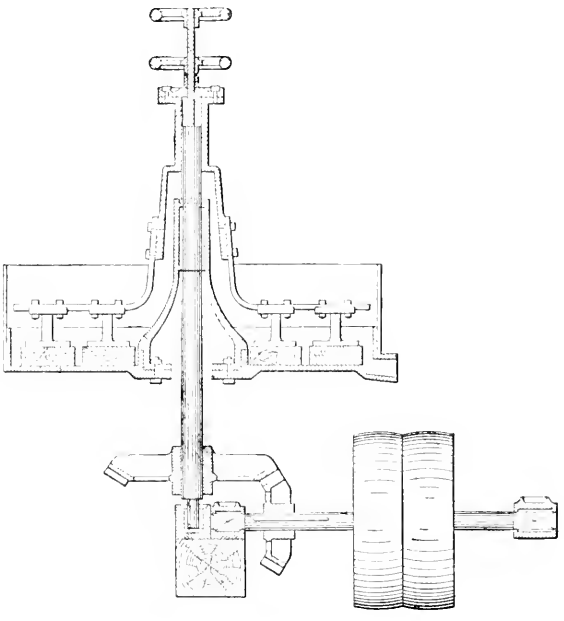


Fig. 256.—Clean-up Pan.

The *sand sluice* can be employed with advantage wherever blanket sluices are used, and if placed before them will relieve them from much coarse and heavy material. They are formed of a long shallow wooden trough from 20 in. to 24 in. wide, in which vertical guides are placed at intervals of from 8 ft. to 10 ft. Into these guides thin riffle pieces are slipped, which act as shallow dams; the sands run over these for a time, say for one or more hours, when another course of riffles, $\frac{1}{2}$ in. or so thick, is laid on top of the others. This is repeated until the sluice is full, when it is shovelled out, the tailings in the meantime running through a duplicate sluice. The inclination at which the sluice is laid is about $3\frac{1}{2}$ in. in 16 ft. The current is then under control; for, by

starting with a thin riffle at the bottom, a strong current may be obtained, and a thick one may reduce it as may be required.

The Boss Continuous Process.—In the process of wet crushing of silver ores, which has just been described, it will have been noticed that the pulp, after leaving the battery, is allowed to settle in vats, and that the solid matter is then shovelled into the amalgamating pans. All this handling is costly and takes up time, and the attention of inventive

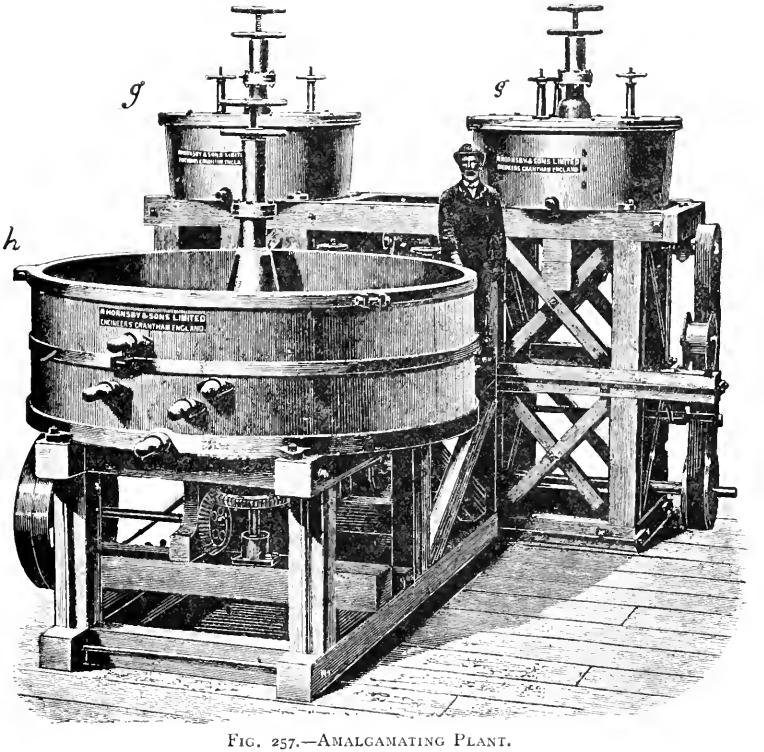


Fig. 257.—Amalgamating Plant.

men has long been turned to devising some scheme by which it could be avoided, so that the pulp might flow on in a continuous stream from the screens through the grinding, amalgamating, and settling pans, leaving its rich contents on the way, and passing from the mill in the state of sterile slimes, without its progress being interrupted by any settling tanks.

Mr. M. P. Boss, an American metallurgist, has devised and put into successful practice such a process; and from the experience already gained, it would appear that it can be successfully applied to any ores adapted to pan treatment, with a considerable saving in time and cost.

A plan and section of a 30-stamp silver mill for the Boss continuous process is given in figs. 258 and 259. The ore from the mine arrives by the tramways (*a*, *a*) and is tipped over the grizzlies (*b*, *b*), afterwards

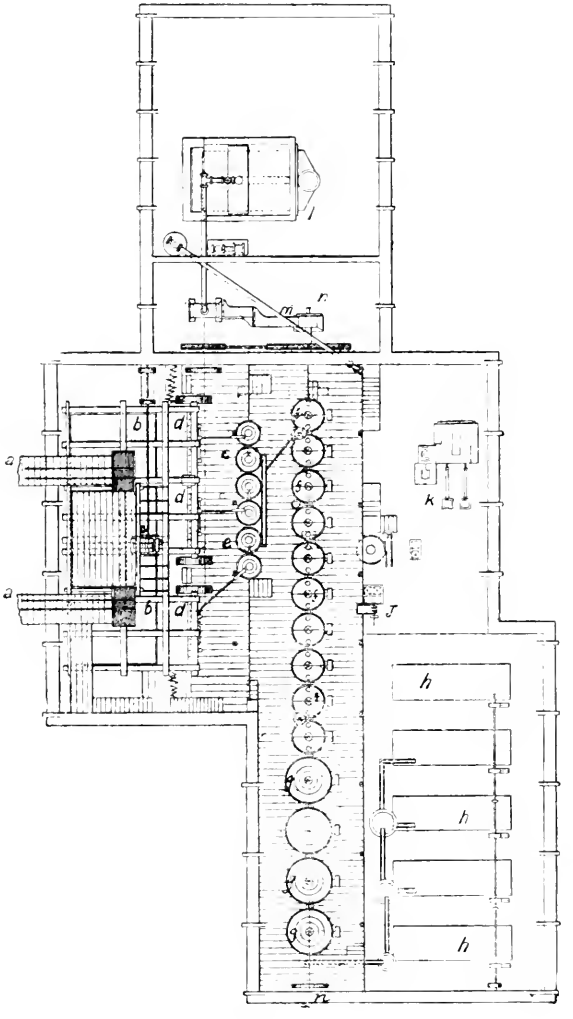


Fig. 258.—30-Stamp Silver Mill, Boss Continuous Process (Ground Plan).

passing through the stone-breaker (*c*) into the bin below, and on through automatic feeders into the line of 30 heads of stamps (*d*, *d*) which discharge their pulp into the grinding pans (*e*, *e*), of which there are two

to each 10 heads of stamps. The product of 10 stamps passes through two of the special grinding pans in succession, and is then conveyed by a suitable pipe to the first of a series of ten amalgamating pans (*f*, *f*) through which it passes in succession, and on into the line of four settlers, (*g*, *g*) from which the tailings flow to the Frue vanners (*h*, *h*). On these the sulphides are concentrated, and any globules of amalgam which may have escaped the settlers are caught, so that when the tailings leave the mill they are practically sterile. With some ores the concentrators are not required. The pans are heated indirectly through their hollow bottoms by means of the exhaust steam from the engine (*m*), which is supplied from the boilers (*l*).

The quicksilver is charged into the pans by means of pipes from the

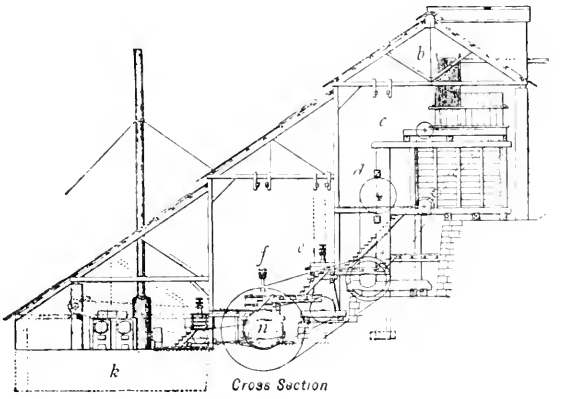


FIG. 259.—SECTION OF A 30-STAMP SILVER MILL, BOSS CONTINUOUS PROCESS.

distributing tank, and the amalgam flows through suitably arranged pipes to the strainer, the mercury being returned to the tank by means of an elevator (*j*). The amalgam is retorted in the furnace (*k*) and the bullion melted into ingots.

The chemicals are supplied by means of two chemical feeders, and steam syphons are used for cleaning out the pans and for carrying the pulp past any one of them which it is necessary to cut out for repairs. The main line of shafting runs directly under the pans and settlers, each of which is driven from it by means of a friction clutch. This arrangement of separate clutches for each pan and settler is very convenient, as any number, or any one pan or settler, can be stopped in case of accident, or for cleaning purposes, without having to stop the whole line.

The whole of the water from the battery must pass through all the pans, so that even the finest slimes are subject to the amalgamating action, and no settling tanks or agitators are required.

CHAPTER XXI.

THE MILLING OF SILVER ORES (continued).

Dry Crushing Silver Mill—Specification of 10-Stamp Mill—The Leaching or Lixiviation Process—Roasting—Lixiviation—Description of Mill—The Leaching Vat—The Precipitation Vat—Acid Pumps—Quicksilver Elevator—Belt Elevator—Chain Elevator—Centrifugal Pumps—Tailing Wheel.

Dry Crushing Silver Mill.—A modification of the silver mill is necessary when the ore contains a large proportion of sulphides, and can no longer be treated by the wet crushing process. The arrangements for a dry crushing silver mill of the modern type are shown in section in fig. 260, and plan in fig. 261. The main alterations consists of drying and roasting the ore before amalgamation, the latter process being identical with that used in a wet crushing mill. The operation of roasting is described on page 422, and is identical with the same process required for the treatment of refractory gold ores before chlorination, except that salt is employed in order to convert the silver compound into chloride of silver in the furnace.

The ore from the mine is elevated to the top of the mill by means of the hoist (*a*) or may arrive direct along the platform (*b*). It is then tipped over the grizzly (*c*) and crushed in the breaker (*d*), whence it falls into the bin (*e*) and is fed by the automatic feeder (*f*) into the revolving dryer (*g*), and, after being deprived of all its moisture, passes on through the chute (*h*) into the feeder (*i*), and so to the dry crushing stamps (J) of which there are twenty, arranged on the line (J J) of the plan. After pulverisation, the ore is elevated and conveyed by the screw conveyers in the troughs (*l l*) to the chimney end (*m*) of the revolving roasting furnace (*m n*). In the furnace the ore is desulphurised and chloridised and is so prepared for the pans and settlers. Leaving the roasting furnace—which may be one of the well-known types, some of which are described in Chapter XXIII.—the ore is spread upon the cooling floor (Q), and is afterwards charged into waggons running on the rails (R R) and shovelled into the amalgamating pans (S S) of which there are ten,

and afterwards the pulp is treated in one or other of the five settlers (*t t*); the amalgamation and subsequent operations are similar to those described

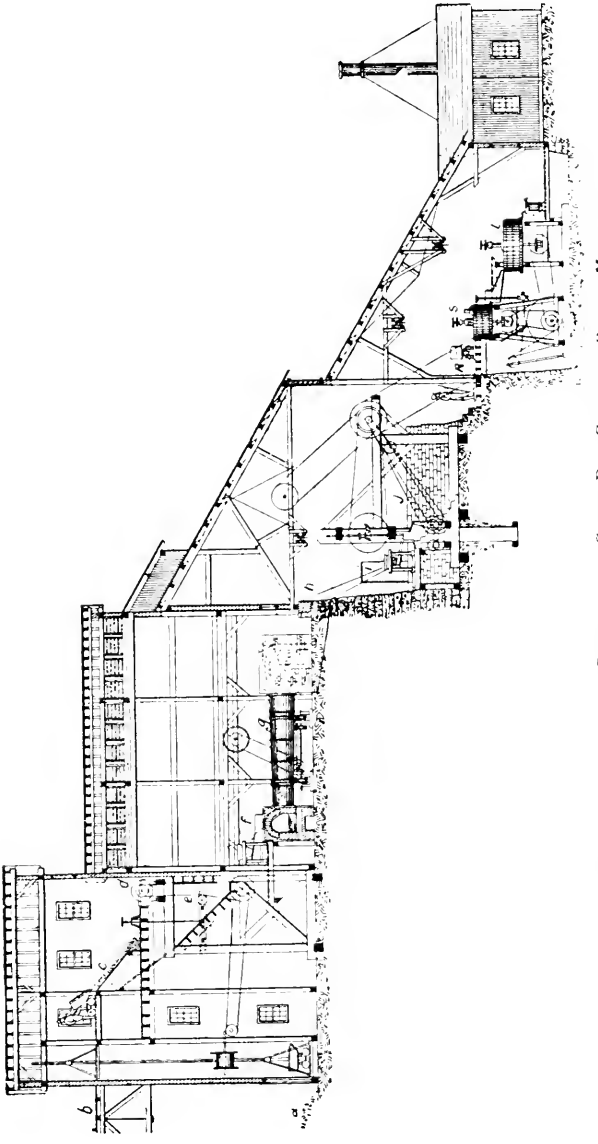


FIG. 260.—LONGITUDINAL SECTION OF 20-STAMP DRY CRUSHING SILVER MILL.

for the wet crushing process. The mill is driven by the engine (*v*) and the boilers (*w*). The amalgam is retorted, and the bullion melted in the

retort house (*w*). Instead of the amalgamation, the lixiviation process could be used with some classes of ore.

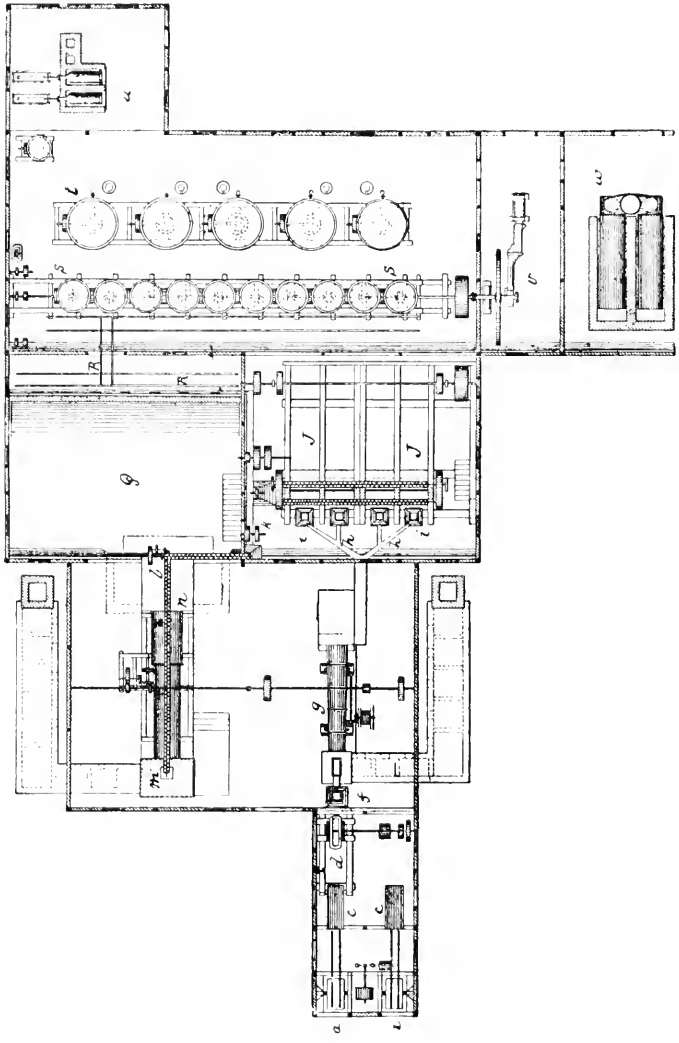


FIG. 261.—GROUND PLAN OF 20-STAMP DRY CRUSHING SILVER MILL.

The power required for a 10-stamp dry crushing silver mill, such as that just described, and as specified in the detailed specification below, would be :

1 Black rock-breaker, No. 2	6	horse-power.
2 ore feeders	0	,,
10 stamps, 750 lb., 90 drops	12	,,
1 Howell-White furnace, 40 in.	4	,,
4 amalgamating pans, 5 ft. diameter	8	,,
2 settlers, 8 ft. diameter	6	,,
Friction	9	,,
Total	45	,,

The water required for the boilers, pans, and settlers would be somewhat less than 1000 gallons per hour.

Specifications for 10-Stamp Dry Crushing Chlorodising Silver Mill (Steam Power).

Boilers :—

2 Fraser & Chalmers' tubular steam boilers, each 48 in. diameter × 14 ft. long, all complete as per specifications attached.

1 Fraser & Chalmers' Corliss steam engine, size 14 × 42 in., all complete in detail as per specifications attached. Crank shaft to be fitted with suitable size clutch coupling for coupling to pan line shaft.

1 Fraser & Chalmers' tubular steam heater, 24 in. diameter, all complete in every respect.

1 No. 4 Knowles' boiler feed pump for feeding boilers with water.

All necessary steam, exhaust, and feed pipes to properly connect boilers, engine, heater, and feed pump.

Grizzly :—

1 grizzly or ore screen for relieving crusher, size 4 × 10 ft., made from 2 × 1 in. iron with washers between. Rods to connect bars, with nuts for same.

Crusher :—

1 10 × 7 Blake crusher, all complete ready to run when set in place.

Automatic Feeders :—

2 Tulloch automatic ore feeders for stamps, with wood frames and sheet iron hoppers.

All necessary track iron, punched and countersunk, with wood screws for laying same for feeders to operate upon.

Stamps :—

1 10-stamp mill of improved design, each stamp weighing 900 lb., arranged to run in one battery of 10 stamps by bolt and tightener from stamp countershaft, all complete in detail as below.

2 high mortars, double discharge, planed upon bottom and faced for screen frames. Foundation bolt holes drilled by template.

4 wood screen frames, fitted to mortars.

8 wrought iron keys for holding screen frames in place.

4 brass wire cloth screens of such size as may be required.

10 patent stamp shoes.

10 patent stamp dies.

10 stamp heads, bored for stems and recessed for shoe stem.

10 stamp stems, made from extra refined iron, both ends tapered; ends being tapered, when one end breaks the stems can be reversed and other end used.

10 tappets with wrought iron gibs and steel keys, all properly fitted to place, faces turned.

10 cams (one-half right and one-half left hand), fitted to cam shaft with steel keys all properly marked to place to give proper drop.

1 heavy hammered iron cam shaft, turned full length and key-seated for pulley and cams.

2 wrought iron collars with steel set screws, fitted to cam shaft.

3 heavy corner cam shaft boxes, babbitted and bored, planed upon back and bottom and furnished with bolts and caps. Boxes to be babbitted with best composition metal.

2 jack shafts, not turned.

4 jack shaft boxes.

10 iron sockets for wood levers, lined with leather.

10 wood levers or finger pieces for holding up stamps, fitted to sockets.

1 pair of double sleeve flanges for wood pulley, turned and fitted together with woodwork built up between, hubs key-seated, woodwork turned up, painted, and securely bolted through flanges.

All necessary bolts, rods, nuts, and washers for 10 stamp, framework complete, including all holding down bolts and washers for mortars.

1 complete set of hard wood guide boxes for ten stamps, all worked out for stamp stems, with all guide bolts, nuts, and washers.

4 sheets of rubber packing, each $\frac{1}{4}$ in. thick, for top of mortar blocks for mortars to rest upon.

Roasting Furnace:—

1 improved Howell-White roasting furnace, 52 in. diameter at small end, 62 in. diameter at large end × 27 ft. long, made in 8 sections, $\frac{3}{4}$ in. thick, sections faced and bolted together with $\frac{5}{8}$-in. bolts, with all fixtures and fittings necessary to make the furnace complete in every respect as usually furnished, including carrying rollers, gearing, pulleys, vertical shafting, fire front, grate bars, etc.

1 smoke stack, 42 in. diameter × 60 ft. long.

400 ft. $\frac{3}{8}$-in. guy rope.

1 base plate for stack.

1 set of fire tools for the above furnace.

Revolving Dryer:—

1 revolving dryer made of cast iron, 44 in. diameter at large end, $36\frac{1}{2}$ in. diameter at small end × 18 ft. long, made in sections, all properly turned and faced, drilled and bolted together with $\frac{5}{8}$-in. bolts; dryer to be furnished complete with fire front, grate bars, bearings, binding bars, tie rods, gearing, boxes, truck wheels, sole plates, for bearings, countershafts, tight and loose pulleys, and everything necessary to make dryer complete in all respects.

1 smoke stack for dryer, 24 in. diameter × 50 ft. long.

300 ft. of $\frac{5}{8}$-in. galvanised iron guy rope.

1 cast iron base plate for smock stack.

Feeder for Dryer:—

1 Tulloch ore feeder for feeding dryer from ore bins, to be furnished complete with countershaft and pulleys.

All necessary track iron, punched and countersunk, with wood screws for laying same for feeder to operate upon.

Sheet Iron Chute :—

1 sheet iron chute from dryer to self-feeders at stamps.

Pans :—

4 improved combination amalgamating pans, each 5 ft. diameter, with wood staves, to be furnished with upright cone in bottom upright spindle, fitted with separate steel toe, 2 hand-wheels and screw on top of spindle for raising muller nut for screw driver sleeves, driver arms separate from sleeves and bolted to same, muller plate, 8 cast iron shoes and 8 cast iron dies to each pan, wrought iron bands and lugs for staves, step box fitted on plate, which also carries one bearing of countershaft ; step box to be fitted with steel buttons and bushings, countershaft, driving pulley, out end bearing for shaft, all bolts for boxes and for bolting to framework.

Settlers :—

2 8-ft. improved combination settlers with wood staves, to be complete in every respect as pans above, the enumeration being the same excepting shoes and dies, wooden shoes, and dies being furnished for the settlers.

Clean-up Pan :—

1 30-in. clean-up pan, with iron sides, complete in every respect. Fitted with cone pulley for changing speed.

Ore Bin Gate :—

1 ore gate complete for ore bins, with rack, hand-wheel, slide, and plate.

Ore Gate for Dryer Pit :—

1 ore gate complete for dryer pit, with rack, hand-wheel, slide, and plate.

Retort :—

1 14-in. silver retort complete, including cover, bar, and nut, screw for holding cover in place, 3 retort carriers, fire fronts complete, with doors and liners, dead plate, back bearers, 2 double grate bars, condensing pipe, cast iron ashpan, wall binders and rods for bracing brickwork, and all necessary fittings required for the complete erection.

Bullion Furnace :—

1 set of castings for 16-in. bullion furnace top, including cover, bearing bars, grate bars, anchor bolts, and all fixtures and fittings belonging thereto.
6 assorted black lead crucibles and covers.
1 set of trays or cups, for holding amalgam.
1 pair of crucible tongs.
2 1000-oz. bullion moulds.
1 500-oz. bullion mould.
1 set of steel numbers for stamping bullion bars.
1 smoke stack for retort bullion furnace, 20 in. diameter × 30 ft. long, with base plate and guy ropes for staying same.
1 set of iron floor plates for retort room floor, with all necessary screws for laying same.

Overhead Crawls :—

3 overhead carriage crawls complete.

Pulley Blocks :—

2 2-ton (Yale and Towne) differential pulley blocks, with endless chain.
1 1-ton (Yale and Towne) differential pulley block, with endless chain.
160 ft. $1\frac{1}{2} \times \frac{1}{4}$ in. track iron, punched and countersunk, with wood screws for laying same.

Battery Conveyers :—

2 battery conveyers with 8-in. flights, each conveyer 16 ft. long, to be furnished complete, with shafts, pulleys, pillow blocks, and collars.

Roaster Conveyers :—

3 roaster conveyers with 10-in. flights, each conveyer 16 ft. long, to be furnished complete with pulley, chain wheels, and bearings.

Quicksilver System.

Elevator :—

1 complete quicksilver elevator, with rubber belt, Russia iron cups, and all fixtures and fittings required for making elevator complete in every respect.
1 each upper and lower quicksilver tanks.
2 quicksilver charging pots for pans, size 12 × 12 in.
2 amalgam safes with strainers complete, with padlocks and duplicate keys, with all necessary fittings and fixtures to make same complete.
1 amalgam car, complete.
120 ft. half-round track iron, with spikes for laying same for car to operate upon.

Quicksilver Piping :—

All pipes, iron cocks, and fittings for the complete quicksilver circulation system that may be required in accordance with our drawings and necessary to make system complete in every detail.

Tighteners :—

1 main tightener for 16-in. belt, to be furnished complete with pulley, boxes, screws, hand-wheel, nuts, and frames.
4 pan tighteners for 12-in. belt, with improved angle iron frames, shafts, pulleys, wrought iron yokes, chains, upright shafts, step and guide boxes, hand-wheels, and plates.
1 crusher tightener for 7-in. belt, with pulley, boxes, shaft, step, pinion ratchet, plate, dog- and hand-wheel, rack, wood frame, and bolts.

Dust Pipes :—

1 complete set of galvanised iron dust pipes for removing dust from battery.

Exhaust Fan :—

1 Sturtevant monogram exhaust fan of suitable size, with countershaft complete for above dust pipes.

Water Pipes :—

All water pipes, valves, and fittings necessary for the complete mill for supplying pans and settlers, with necessary steam and water, ready for receiving connection with main water supply.

Memorandum.

Sufficient pipe for connecting with tank or mill supply is not included.
1 hot ore car, complete, made entirely of iron.
2 ½-ton scoup ore cars, with iron bodies, 18 in. gauge.
1 set of ironwork for transversal car, with axles and wheels.
180 ft. of 12-lb. tee rail, with spikes and joints for laying same for cars to run upon.
All necessary bolts, rods, nuts, and washers for the complete framework of mill building in accordance with the drawings as usually furnished.
7 complete sets of ore gates for pulp bins, with levers, slides, and plates.

Elevators :—

1 ore elevator complete, comprising :—
1 shaft $2\frac{15}{16}$ × 5 ft.
2 pillow blocks $2\frac{15}{16}$ in.
2 pulleys 36 × $8\frac{1}{2}$ in.
1 shaft $2\frac{7}{16}$ in. × 2 ft. 6 in.
2 pillow blocks, $2\frac{7}{16}$ in.
1 pulley 16 in. × $8\frac{1}{2}$ in.
All necessary collars, bolts, and steel set screws.
88 7-in. Duc's heavy elevator buckets.
176 bolts for attaching buckets to belt.
125 ft. 8 in. 5-ply endless rubber belt for elevator, belt punched with holes for attaching buckets.

Shafting, Pulleys, and Boxes :—

All necessary shafting, pulleys, boxes, and belting for driving all of the above described machinery in accordance with our drawings.
An assortment of copper rivets and burrs.
Total approximate weight, 265,000 lb.

ADDENDA.

Smoke Stacks :—

In the above estimates are included smoke stacks for both roasting furnace and revolving dryer. If, however, it is desired to build stacks of brick, omit the smoke stacks included. Brick stacks are only practicable in some localities, and it will be found that iron stacks such as are included are the cheapest, being much more easy to erect. Stacks rolled, punched, and shipped K. D., in crates when desired : usually shipped in riveted sections of 20 ft.

Firebricks for Roasting Furnace :—

For lining the 60-in. Howell-White roasting furnace, 3040 special shaped firebricks are required. Sometimes this firebrick can be purchased near the mines. If, however, it is desired to have this brick shipped with the machinery the following is the cost and weight :—
3040 special shaped firebricks, weight about 36,500 lb., cost about $310, f. o. b. cars, Chicago.
For this amount of firebricks, about two barrels of fireclay would be required, each costing $4, and weighing 500 lb. each.
This mill as covered by specifications is complete and automatic.
Patent sectional stamp guides are recommended instead of ordering guides as specified above.

The Leaching or Lixiviation Process.—This process effects for refractory silver ores what the chlorination, or the McArthur-Forrest process, does for similar gold ores, and consists in first roasting the ore with salt, in order to convert the silver into chloride of silver, and then dissolving the chloride in hyposulphite of soda, from which it is afterwards precipitated in the form of sulphide of silver by the addition of a solution of sulphide of lime or soda. The Russell process, which is a

modification of this, consists chiefly in the addition of a certain proportion of sulphate of copper to the hyposulphite solution.

The leaching process can be applied to all ores adapted to roasting amalgamation, as well as to the more refractory ones, and has, indeed, some advantages over that operation, in that the cost of the necessary plant is less, as well as the power required. The chief objection to its use arises from the fact that the chemical reactions involved are often complicated, and liable to sudden disturbances, owing to slight changes in the character of the ore. Another difficulty exists in the small number of men available to take charge of such works, owing to the thorough chemical knowledge which is essential, combined with the practical experience and good judgment necessary in the manager of a mining undertaking.

The process was introduced into Mexico in 1868 by Mr. Ottokar Hofmann, and has since come into extensive use in America for the reduction of all classes of silves ores, except such as contain so much lead that they can be smelted direct, or those which, on account of the clayey nature of their gangue, do not permit of free filtration.

Roasting.—The ore is first crushed and stamped dry in the usual way, and is then roasted in any of the kilns or cylinders in ordinary use for gold or silver ores, with the addition of salt in order to convert the silver into silver chloride, as described on page 422. For the successful roasting a sufficient quantity of mineral sulphides should be present, in order that by their decomposition they may produce sulphuric acid, which, in its turn, acts upon the salt, and so liberates the chlorine gas necessary for the formation of chloride of silver. The base metals present in the ores are converted into oxides, chlorides, and sulphates. The amount of salt required varies from 4 to 10 per cent., according to the nature of the ore. As in the amalgamation process, the roasting is the most important operation, and must be conducted with great care.

The salt is added either before the ore enters the furnace or afterwards, when the excess of sulphur has been driven off and the oxidising roasting begun.

Lixiviation.—When the ore has been properly roasted it is moistened with water, and shovelled into wooden tubs in charges of from 10 to 15 tons. These leaching tubs are described on page 403, and are provided with a central discharge around which a filter bottom is arranged in the form of a flat funnel. The filter cloth is kept in place by ropes driven into grooves around the discharge hole and the inner circumference of the vat near the filter bottom.

The vat is furthermore provided with an outlet under the filter bottom, and has a slight inclination towards this outlet. The charge of roasted ore in the vat is leached with water in order to remove the soluble salts of the base metals. The silver chloride is insoluble in water; but if the

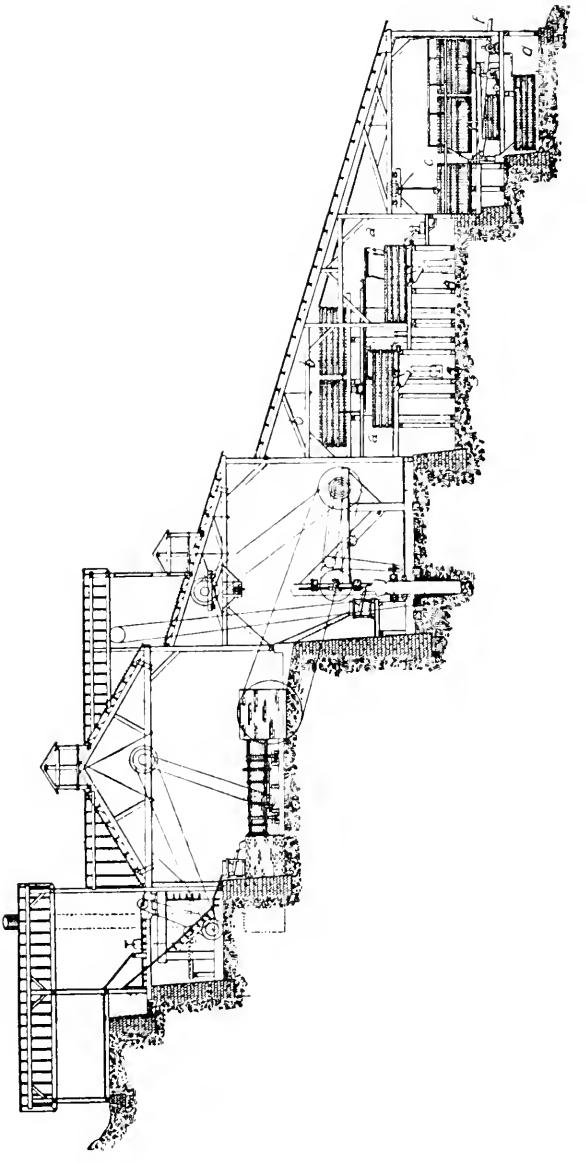


Fig. 262.—Longitudinal Section of Lixiviation Mill, with Hofmann's Roasting Furnaces.

charge is too thick the water becomes so saturated with the chlorides of the other metals as to become a partial solvent of silver chloride. For this reason the charges should not be too heavy. The leaching with water is continued until the whole of the soluble chlorides are dissolved

out, which may be tested by the addition of a few drops of calcium polysulphide to a test-tube full of the outflowing liquor. If no discoloration takes place the leaching may be stopped; but this cannot usually take place under a period varying from 4 to 10 hours, according to the nature of the ore under treatment.

After the removal of the soluble salts of the base metals, a stream of a dilute solution of hyposulphite of soda is allowed to enter on top of the ore, and this readily dissolves the chloride of silver. The outgoing solution is now conveyed into special precipitating tanks, and in these the silver is precipitated by the addition of calcium polysulphide. The form of tank used is shown in fig. 263, and the precipitation is hastened by the action of the revolving stirrers. The clear solution of sodium hyposulphite is now decanted off, and is ready for use again; and if the operation is skilfully performed this solution can be used over and over again for years. As soon as a sufficient quantity of sulphide of silver has accumulated in the bottom of the precipitating tanks, it is drawn off and strained through properly arranged filters of cotton cloth. It is then charged into a reverberatory furnace, and, after roasting, is melted with lead in a cupelling furnace and refined.

The tailings are sluiced out from the leaching tanks, and fresh ore is then charged into them. The wear and tear of the lixiviation plant is insignificant, and the wood is prevented from decaying by the action of the base metal salts. The calcium polysulphide, which is used as a precipitate, can be manufactured on the works by boiling two parts of fresh lime with one part of pulverised sulphur in water for 3 or 4 hours, in deep iron tanks, into which steam is directly introduced The consumption of sulphur varies from 2 lb. to 7 lb. per ton of ore, and that of the lime at about double the amount, according to the nature of the ore. These, and the salt, are the only chemicals used.

Lixiviation Mill.—The general arrangements of a lixiviation mill are shown in fig. 262. The ore is crushed, dried, stamped, and roasted, as in the case of dry silver milling; the pulverised and roasted ore is then charged into the leaching tanks (*a a*) where, after having been washed in order to remove the soluble compounds, it is leached by a stream of hyposulphite of soda stored in the tanks (*b b*). The silver in solution is then run off into the precipitating tanks (*c*) when, after its precipitation, the renovated sodium hyposulphite is decanted off into the vat and pumped back by means of the pump (*f*) into the tanks (*b b*). The waste sands are sluiced out of the leaching vats and leave the mill by means of the chutes (*g g*). The whole arrangement is practically automatic, and were it not for the unforeseen chemical reactions set up occasionally by the changing nature of the ores, might, with advantage be used in preference to the amalgamation process.

Special Appliances.—The special appliances used in a lixiviation mill

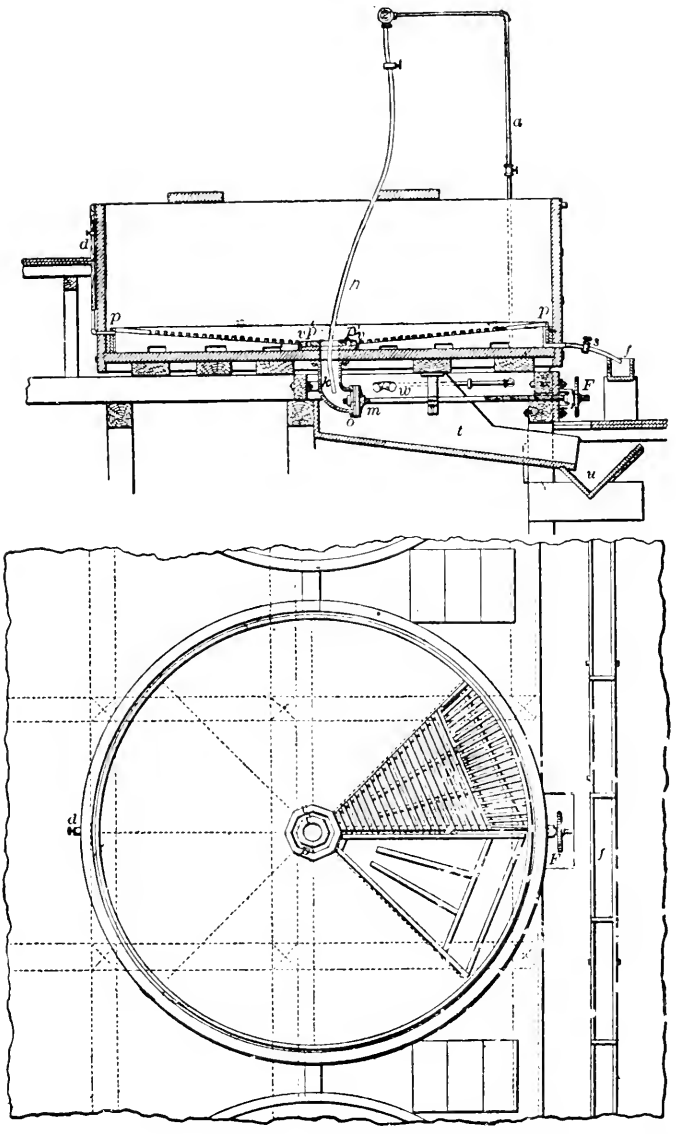


Fig. 263.—Leaching Vat, with Sluicing Arrangement (Plan and Section).

instead of amalgamating pans and settlers, are leaching vats, precipitating vats, and acid pumps

The power required to drive the stamps, dryers, and roasting furnaces as well as the amount of water necessary, will be found on pages 395 and 470.

The Leaching Vat.—A vertical section and plan of this is given in fig. 263. The discharge opening is situated in the centre of the bottom, and is 6 in. in diameter. Beneath this, on the outside, the curved discharge tube (K), of the same diameter, is fixed. This tube is kept closed by the presence of the valve (M) and the screw (F) against the flange (O). The valve and the flange are of brass.

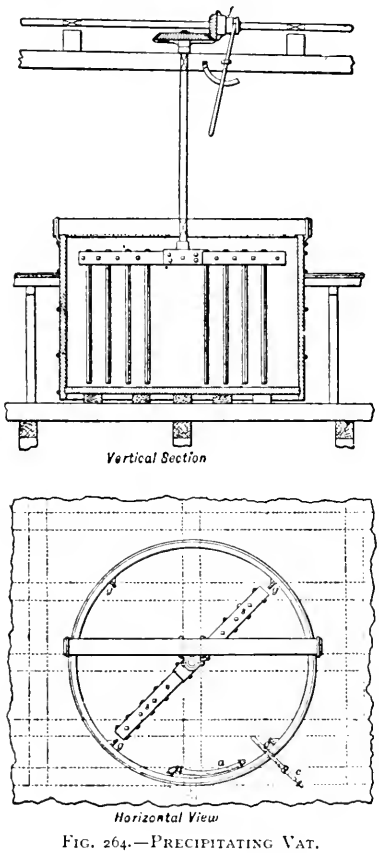


FIG. 264.—PRECIPITATING VAT.

The wooden grating (V) slopes upwards from the discharge opening (K) and around the outer (P) and inner (P^1) circumference of this the circular grooves (P) and (P^1) are formed, into which the filter cloth is wedged with rope. The slope of the grating (V) is $\frac{3}{4}$ in. to a foot. The air escape pipe (D), which reaches to the rim of the tank, enters the latter close under the filter bottom. It is provided with a tap for closing it when necessary. Z is the water pipe; N is the central hose pipe, which reaches down to the discharge pipe (K), where it has to remain during the process of charging. This hose should be very stiff in order to prevent it from collapsing under the pressure of the contents of the vat. Before charging the tank, the discharge pipe is filled with water in order to prevent the inside of the hose from being blocked with ore.

When a tank is ready to be discharged, the wheel (F) is turned, and the valve (M) thus withdrawn. Water is now turned on through the central hose, which is moved up and down gently so as to undermine the tightly packed sand and cause it to fall in. Water is then turned on at the top, while the hose still at work prevents the blocking of the pipe (K). The sterile sands are carried away by the chute (*t*) into the sluice (*u*) which carries them out of the mill.

The silver solution is drawn off by means of the pipe and tap (*s*) and led by the trough (*f*) into the precipitating vat.

The Precipitation Vat (fig. 264) is provided with a wooden stirrer of the construction shown, driven by the gearing (*f*) at the rate of about

30 revolutions per minute if the diameter of the tank does not exceed 8 ft. or 9 ft. In order to break the violent motion of the current, the wings (G), which are about 3 in. wide, are fixed inside the vat, and throw the solution back towards the centre.

The discharge pipe for the clear solution is shown at A in the section (fig. 264), and also in the plan; and B is that used for the precipitate.

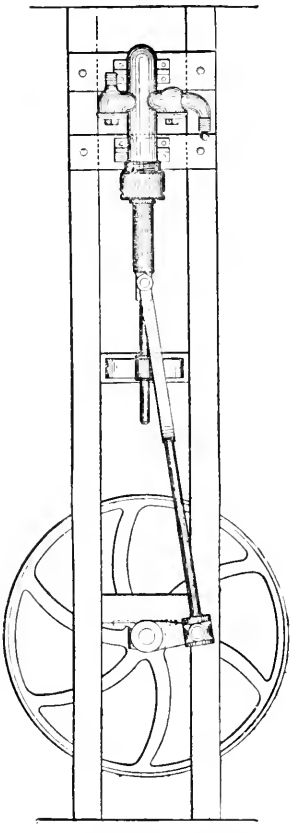


FIG. 265.—ACID PUMP OF HARD RUBBER, OR COPPER BARREL, WITH RUBBER PLUNGER AND RUBBER VALVE.

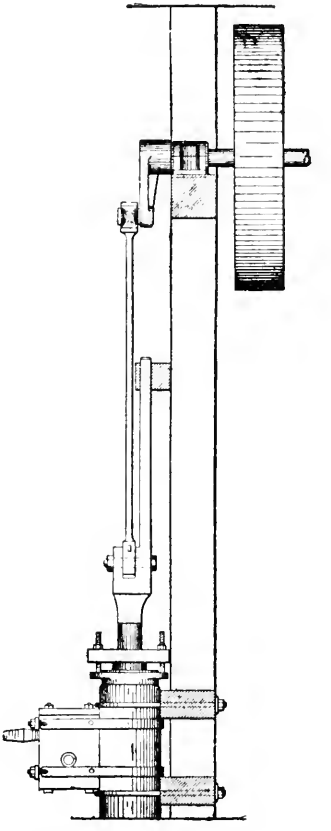


FIG. 266.—ACID PUMP OF WOOD AND RUBBER.

The branch pipe (C) reaches above the rim of the tank, and ends in a rubber hose which is provided with a clamp. In precipitating, the stream of calcium sulphide can be regulated, and the operator, by observing the colour produced by the precipitant in the moving liquor, can, after some practice, finish the operation quickly and more effectually than by the use of buckets.

One man can precipitate three tanks at a time; and owing to the thorough agitation of the liquid a perfect separation of the silver sulphide can be obtained; so much so, that the bottom of the tank can be distinctly seen through 5 ft. of solution.

Acid Pumps.—The strongly acidulated waters required in the leaching process necessitates the use of an acid pump, such as that shown in fig. 265, which is built of hard rubber or copper—by preference the former—and fitted with a rubber plunger and valves. This class of pump is the best for the purpose, but is expensive when made entirely of rubber; so that where expense is an object, a pump made partly of hard white wood with hard rubber valves, bound together by copper straps and bolts, as shown in fig. 266, can be employed. Both pumps are driven by belting from the shafting of the mill.

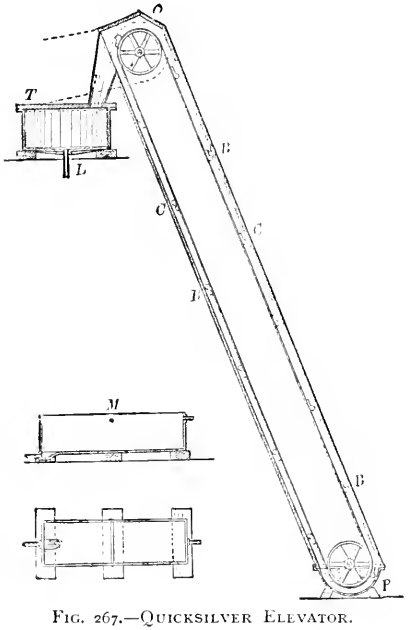


FIG. 267.—QUICKSILVER ELEVATOR.

Quicksilver Elevator.—The weight and fluidity of mercury both combine to make it a very difficult thing to handle without loss. Formerly it was the custom to carry it about the mill in buckets; and then, at a more recent date, and as indeed is now the practice in some mills, a system of pumps was erected by means of which the mercury was pumped back from the pans into a reservoir at the top of the mill, and thence distributed in pipes to the various appliances. The pumping of mercury, however, entails considerable difficulty in practice, and is now being superseded by the use of an elevator of much the same form as the ordinary belt elevator. The remainder of the pipe system is the same as when a pump was used, starting from the receiving tank at the top of the mill.

The elevator cups (B B) are made of Russian iron, and are of the peculiar shape shown in fig. 267, which is especially adapted for carrying quicksilver. The lower pulley (P) and bearings are carried by a cast iron boot, to which, and extending up to and around the upper pulley, is attached a wooden, or, preferably, a sheet iron casing (*c*), the joints of which must be made perfectly tight in order to avoid loss of any quicksilver spilled from the cups. The upper tank (T) receives all the quicksilver, and like the lower is made of cast iron.

The distributing pipe (L) leads off from the bottom, and from this the other pipes branch off as required. The tank (M), shown in plan and section, is a receiving tank made of cast iron, in which the quicksilver returned from the mill is collected previous to being again elevated.

The amalgam in the pans and elsewhere in the mill is collected in lock-up sheet iron safes of a portable form; and in large mills sheet iron cars running on rails are used. These, however, as well as the distilling and smelting furnaces, can hardly be classed as machinery, and the reader is referred to the books already mentioned for the details of distilling mercury, assaying ore, and smelting bullion.

Ore Elevators.—*The Belt Elevator.*—In the designing and arranging of concentration mills of all types, the one great point to be kept in view is to make them automatic, so that the ore once fed into the crusher may afterwards pursue its way, by gravitation if possible, through the whole series of machinery.

For this purpose it is usual to build the mills on the slope of a mountain side, but even then it is not always possible to ensure absolute automaticity without calling some mechanical devices into play. This almost invariably occurs in dry crushing silver mills; and in order to convey the dry pulp from the stamps to the roasting furnaces, a belt elevator must be used in connection with screw conveyers. The belt elevator, shown in fig. 268, consists of a series of sheet iron cups attached at regular intervals to an endless belt passing over pulleys. The crushed and dried pulp from the battery is conveyed into the boot of the elevator by means of screw conveyers and is then lifted as fast as it is delivered to the hoppers overhead, from which it either falls direct, or is again conveyed into the hopper of the roasting furnace. The elevators and conveyers must be surrounded by a wooden casing to prevent the escape of dust into the mill. The capacity of the elevator depends upon the number of buckets and the speed of the pulleys, and these are adjusted by the manufacturers to suit the quantity of ore and the height to which it has to be raised.

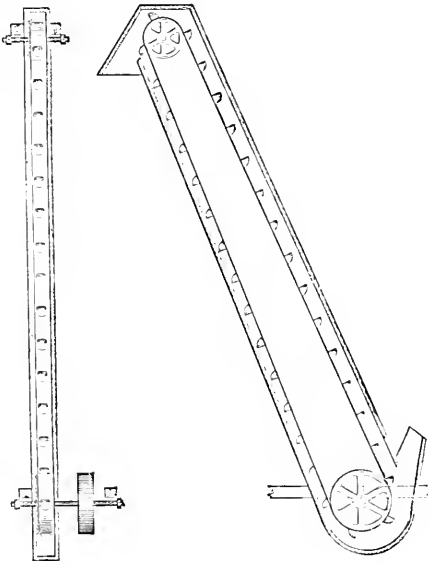


FIG. 268.—BELT ELEVATOR.

My own experience with belt elevators in concentration plants has been uniformly satisfactory. If they are solidly constructed in the first place they give no trouble, and in my judgment are more satisfactory than chain or link elevators. They will work with wet or dry ore, and should be built with as great a slope as the construction of the mill will permit in order to get a clear discharge at the top. If they are too perpendicular there is a considerable wastage from ore falling back down the return side instead of being thrown over into the shoot.

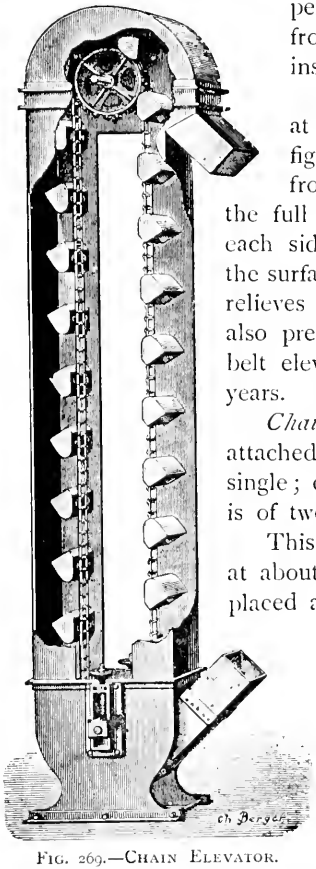


FIG. 269.—CHAIN ELEVATOR.

I usually drive them through spur gearing at the top end, not at the bottom, as shown in fig. 268, as it is difficult to keep the foot clean from mineral. In order to take the weight of the full buckets off the belt, I attach a bracket at each side which slides along a wooden support on the surface of which a strip of iron is screwed. This relieves the belt from a portion of the weight and also prevents it from sagging. A well constructed belt elevator will run continuously for a couple of years.

Chain Elevator.—In this elevator the buckets are attached to a chain, which for ordinary duty may be single; or, when for heavy work and wide buckets, is of two chains, placed side by side.

This form of elevator is shown in fig. 269, running at about 200 ft. per minute, but works best when placed at an angle instead of vertically. The chains work over chain wheels at each end. The shaft of the upper or lower chain wheels is arranged in adjustable bearings, which can be raised or lowered in order to keep the chains tight. Care should be taken that this shaft is kept quite level, and that each chain, if there are two, is equally tight, as otherwise one or other will mount on the teeth of the chain wheels, and the driving belt connected to the spur gearing, which is sometimes used to work the elevator, will be thrown off. If the chain elevator is too small for the work required of it, there will be endless trouble in the mill and a display of language suited to the occasion. The moral is, have your elevator capable doing double the work ordinarily required of it; and then, when any extra strain is thrown upon it, there will be no trouble from stoppages.

Iron Link Elevator.—For heavier work the iron link elevator shown in fig. 270 is to be preferred. The arrangement is somewhat similar

to the last, except that the buckets are larger and are attached to wrought iron links, running over a hexagonal drum at either end, the upper one being driven by gearing.

The links run in angle irons, by which they are supported when rising. I have found this form of elevator to work well in lead-dressing mills for raising the coarse sands and tailings from the jiggers to the pulverising mills, though with all forms of elevator used for raising wet and heavy slimes there is the difficulty caused by the clogging of the ore in the buckets and only a partial discharge. I have endeavoured to get over this by directing a jet of water into the buckets as they arrive at the

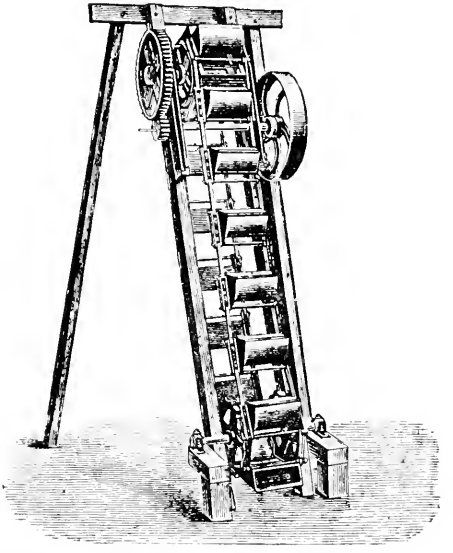


FIG. 270.—IRON LINK ELEVATOR.

summit; and this, although not a perfect remedy, is better than keeping a boy hammering at the buckets with a stick to get them to discharge.

Centrifugal Pumps.—For very wet slimes and pulp I find these to answer better than any form of elevator, as the constant rush of water prevents the heavy mineral from settling. I have used them largely for returning "middlings" from the vanners to a Spitzkasten for further treatment; and provided that the pump is arranged to take a slightly less quantity than that supplied to it, have not had any difficulty in working them continuously for months at a time. If, however, the pump throws more water than that running to it, it will of course stop, and the heavy mineral will deposit itself in the tank and choke the pipes before the pump can be restarted.

Tailings Wheel or Waterwheel Elevator.—The best appliance for

raising the fine slime waters to the height required for the fine concentrators is the waterwheel elevator, which is shown in Plate XII. (fig. 300, page 452), in use at a large lead mill. The slime waters are collected in a pit under the wheel, which is revolved by gearing in the opposite way to the ordinary overshot waterwheel. The buckets dip into the slimes and raise them to the proper height, and then discharge them from the inside rim or back of the bucket into a receiving trough, which conveys them to the concentrators. The wheel is revolved slowly at a speed varying from 2 to 3 revolutions per minute.

The buckets should have a small hole in the bottom of each in order that the slimes may drain away when the mill is stopped, or otherwise, owing to their great weight it is somewhat difficult to restart the wheel, and the driving belt may be thrown off. If this is not done then before the mill is stopped, the water supply should be cut off, so that the wheel may empty both itself and the pit below, and thus avoid difficulty in restarting.

I have had a long experience with one of these wheels and never had cause to complain of it, and for the raising of slime waters I much prefer it to all other forms of elevators.

In fig. 110 (page 151) will be seen an illustration of a tailings wheel, 60 ft. diameter, at the Ferreira Deep Mine. It is driven by the steel cables shown ; but wheels of a smaller diameter are usually driven by means of a pinion and segmental rack. In South Africa wheels of this description are very commonly used in connection with the cyanide plants, the wheels elevating the pulp or slimes from the batteries and discharging them into the cyanide vats, or again raising the waste from the vats and discharging it on to waste heaps. The flatness of the country necessitates some such appliance, and the quantity of stuff to be handled as well as the cost of labour have led to the perfecting of this type of elevator.

CHAPTER XXII.

AMALGAMATING PLATES AND MACHINERY.

Copper Plates—Cleaning and Amalgamating the Plates—The Amalgamator—Conditions Necessary for Good Results—Losses in Amalgamation—Amalgamating Pans—Description of Pan—The Boss Standard Pan—The Wheeler Pan—Settlers—Agitators.

Amalgamating Machines.—When the gold occurs in a free state in the ore, it can be most advantageously extracted by means of the well-known apron of amalgamated copper plates, but when, on the other hand, the precious metal is closely associated with sulphides, the concentrates must be ground down to an impalpable powder in the presence of mercury, with which they are thus brought into intimate contact, so that the finest particles of free gold have every opportunity of becoming amalgamated and retained. The number of machines which have been invented, and in fact are being almost daily invented, for the purpose of the grinding and amalgamating of sulphides, is legion, and their description would require volumes. I purpose, therefore, only to notice a few of the better known appliances which have stood the test of practical work. There is, however, hardly a machine in use of which some good work cannot truthfully be recorded, especially when that particular machine is worked by a man who believes in its superiority, and the whole of whose care and intelligence are devoted to the obtaining of good results with it.

Copper Plates.—First, however, with regard to the apron of copper plates. The plates should be made of the purest and softest copper obtainable, and be perfectly free from dark or rough spots. The quality known as "braziers' coppers" is the best material for the purpose. The width of the plates is that of the mortar box, while the total length employed is from 8 ft. to 12 ft. sometimes arranged in a series of shallow steps, and sometimes in one plain surface. The same width is kept for the full length, and the practice of narrowing towards the lower end should not be followed. The inclination at which they are set varies according to the different ores. Those with light gangues require

but a slight inclination, while those containing heavy sulphides require one sufficient to prevent the settlement of sand on their surface. The weight of the copper should be about 3 lb. to the square foot for the exterior plates, but for those used inside the mortar box a weight of from 6 lb. to 9 lb. per square foot should be used, owing to the liability of the plates being torn or bent by the action of the ore in the box.

Copper sheets with the hard, shiny surface given by rolling after the last annealing, are not suitable, as they are not of sufficient porosity to take up the mercury. If these sheets only are procurable they must be annealed over a blacksmith's, or an open wood fire until thoroughly softened, in which state their capacity for absorbing mercury its greatly superior.

It is of great importance that the plates should have a true, even, and flat surface, and as the action of the mercury is to make them brittle, they must be blocked quite flat before amalgamation. To effect this they are laid on the true surface of the table, and flattened by the use of a block and hammer, the block being interposed between the hammer and the surface, so as to spread the blow over a large area, and so compress the copper into shape. The final flattening operation can best be conducted by screwing the plates down to a board, and when they have been beaten perfectly flat, the next operation is to thoroughly scour and clean one surface. The scouring is accomplished with a hard brush, and plenty of fine sand and water as well as a liberal allowance of elbow grease, which indeed must be the only form of grease allowed near the plates. All other must be removed by a scouring wash, with a solution of caustic soda or potash, and finally, after washing in clean water, they should be brushed over with a weak solution of cyanide of potassium.

This latter is a deadly poison even in weak solutions, and we know of a case in which several bullocks were poisoned through drinking from a reservoir, into which the washings from the mill had been allowed to flow.

When the plates have thus been thoroughly cleaned and brightened, they are ready to be amalgamated. For this purpose they are coated with a mixture of fine sand, chloride of ammonium (sal-ammoniac), and a small quantity of quicksilver. This mixture is scrubbed over the plates with a brush until the whole surface is silvery bright, and the plate will not absorb more mercury. As several plates will be undergoing the process at the same time, the first is left to stand until the others have received their first coating.

No. 1 is then washed in clean water, again wiped over with a weak solution of cyanide, and more mercury rubbed over it until it will take up no more. The process is a long and tedious one, and, good as it is, the plates will not attain to their maximum efficiency as gold

amalgamators, until after a fortnight's run. This is one of the causes why the first milling returns are always unsatisfactory and disappointing.

Many devices have been tried in order to get over this difficulty, so as to start the mill from the very first at its maximum efficiency. One of the best of these is by the use of copper plates, which after the preliminary cleaning have been coated with silver, either by the use of silver amalgam, or by electro-plating. These plates are doubtless more expensive, but when electro-plated to the extent of one ounce of silver per square foot, they are in a first-rate condition for receiving and absorbing the mercury, and will save their extra cost by the extra amount of gold which they will retain during the first week's run.

The duty of keeping the plates in working order devolves upon a skilled employé termed the "amalgamator"; and the following are the general conditions necessary to the successful amalgamation of the particles of gold, as they sweep over the plates in a constant stream from the stamps.

The conditions of a good result from amalgamation* are:

1. Very fine stamping if the ore is fine.

2. A coating of gold amalgam on the plates. No amalgam should be removed until a hard layer of it has been formed on the plates.

3. The use of a proper quantity of water. Too much will result in a coarse crushing, a less complete mechanical exposure of the fine gold, less contact of the gold and quicksilver, and a premature sweeping off of both. The addition of too much quicksilver, though causing the formation of more amalgam, will only lead to its being swept away by the current.

4. Proper temperature of the battery water. The water should neither be too hot nor too cold; 90° to 110° Fahr. is the best, if by artificial means it can be raised to it.

5. The addition of quicksilver in proper quantity. This condition should be closely studied. There is always a considerable loss of quicksilver. The quicksilver introduced into the battery is finely divided by the stamps, and thus affords an opportunity for the amalgamation of the fine particles of gold. By the violent motion in the battery produced by the fall of stamps, particles of gold, amalgam, and quicksilver, are carried away with the pulp to the copper plates, to which they adhere.

6. Proper height of the charge in the mortar. This should not be allowed to rise higher than about 3 in. below the lower edge of the inner plates. If the quartz and pulp in the battery come nearer the plates, too much stuff, which is also too coarse, is thrown upon them, thus either preventing the accumulation of amalgam, or displacing it after collection.

* "The Metallurgy of Gold," by M. Eissler. Fifth edition. London: Crosby Lockwood & Son.

7. Regular feeding.

8. Care in keeping the plates clean.

9. Care in the mill against the introduction of grease or greasy substances, and against the use of exhaust steam of heating water required in any of the amalgamating processes. In lubricating the cam shaft, journals, cams, tappets, or any other portions round the batteries, care must be taken not to drop any lubricant into the mortar.

10. Rejection of hydrated oxidised iron ores, silicate of magnesia and alumina ores. They cause a frothing of the water, and coat the gold with a slime which resists amalgamation.

11. Avoidance of mineral waters for battery amalgamation, especially if they contain sulphur in the shape of sulphuretted hydrogen, as a coating will be formed on the gold particles which prevents amalgamation.

12. Care that the amalgam on the copper plates is not allowed to get too hard, as it may fail to catch the gold. If, therefore, the amalgam should get too hard, it will be well to sprinkle some globules of mercury over it, through a chamois leather. If, however, it becomes too soft there is danger of flouring and losing it with some of the gold.

13. A dilute solution of cyanide of potassium should always be kept in hand, and when any yellow spots appear on the plate, some of the solution should be poured over it. If this does not remove the spot, hold a lump of cyanide over it or rub it, which will have the desired effect.

14. If the ores contain soluble sulphates, arising from the decomposition of iron or copper pyrites, the addition of lime will prove beneficial while passing through the battery.

15. When treating gold ores containing manganese, it is necessary to clean the plates of its adhering amalgam at least once a week, and give them a fresh coating of quicksilver.

16. It will be found that in many cases amalgamation can be promoted by discharging from the batteries on to concentrators direct, which will collect all the heavy mineral particles which interfere with the ordinary amalgamating process, and submitting the concentrates to separate treatment.

The overflow or tailings which pass the concentrators if carried over copper plates will now easily give up the gold, in case any fine particles have escaped in the concentrating process, as the ore has undergone a cleaning process by the separating of the sulphides in the concentrates, which naturally interfere with copper plate amalgamation.

If the concentrates are submitted to treatment in grinding pans the tailings from the settler ought to be run over slime tables to collect any escaping particles of value.

When treating heavy pyritic ore, it will be found of advantage to have an iron pipe with little holes discharging a fine gentle shower of water on the copper plates, so as to assist the carrying off of the heavy

sulphides, which would cover the plates over, and prevent the contact of the free gold with the quicksilver.

The process of amalgamation by means of copper plates is, of course, not a perfect one, and the amount of gold which can thus be recovered will vary between 60 and 70 per cent. of the total amount contained in the gangue. This inefficiency and loss is due to various reasons which may be briefly summarised as follows:

Losses due to the nature of the gangue, which, if it is clayey or talcose, is apt to coat the liberated particles of gold with a greasy slime which prevents their contact with the mercury. Gangues containing sulphides, which also prevent the amalgamating action of the mercury. In some cases also the surface of the gold has become oxidised or rusty, and here also the mercury cannot attack it. Various losses are also due to the action of the stamps in flattening the gold and driving particles of gangue into it, dividing it up into such minute particles that it floats away on the surface of the water. Again, the ore is insufficiently crushed, molecules of sand are left adhering to the atoms of gold, thus raising its specific gravity, and preventing its contact with the quicksilver. The quantity of water supplied will also cause the percentage of gold to vary. If too little is allowed, the plates become coated with sand; if too much, on the other hand, the gold is swept across them. The glorious mean is the point to be aimed at, and can only be attained by close attention and unceasing watchfulness.

Amalgamating Pans.—The heavy concentrates from the blankets and other concentrators of some gold mills are ground up fine together with quicksilver in amalgamating pans, with a view to extract any free gold that may have escaped the action of the plates. The process of grinding in pans is, however, more adapted to the silver than gold milling, and is described under the head of silver milling, the object being to reduce the pulp to an impalpable powder, and at the same time to mix it up with, and subject it to, the amalgamating action of mercury. With this end in view a large number of inventions have been brought out, the general object being to produce grinding surfaces of the most effective form, securing the greatest uniformity of wear with economy of power; to obtain the most favourable conditions for amalgamation, depending mainly on the free circulation of the pulp, the uniform and thorough distribution of the quicksilver, and the proper degree of heat; and to combine with these requirements simplicity and cheapness of construction, facility in management and repair, large capacity, and economy of time, labour, and materials in the performance of duty.

The most approved form of pan is that with a cast iron bottom and wooden sides, as shown in fig. 252 (p. 385). The diameter inside the staves is 5 ft., which, however, may vary a few inches.

The bottom of the pan is mostly protected by cast iron dies (*a*, fig. 252, p. 385), and the muller (*b*) is furnished with adjustable shoes, so that if it is necessary to grind the ore the wearing surfaces may be renewed. The muller is always adjustable by means of the hand-wheel,

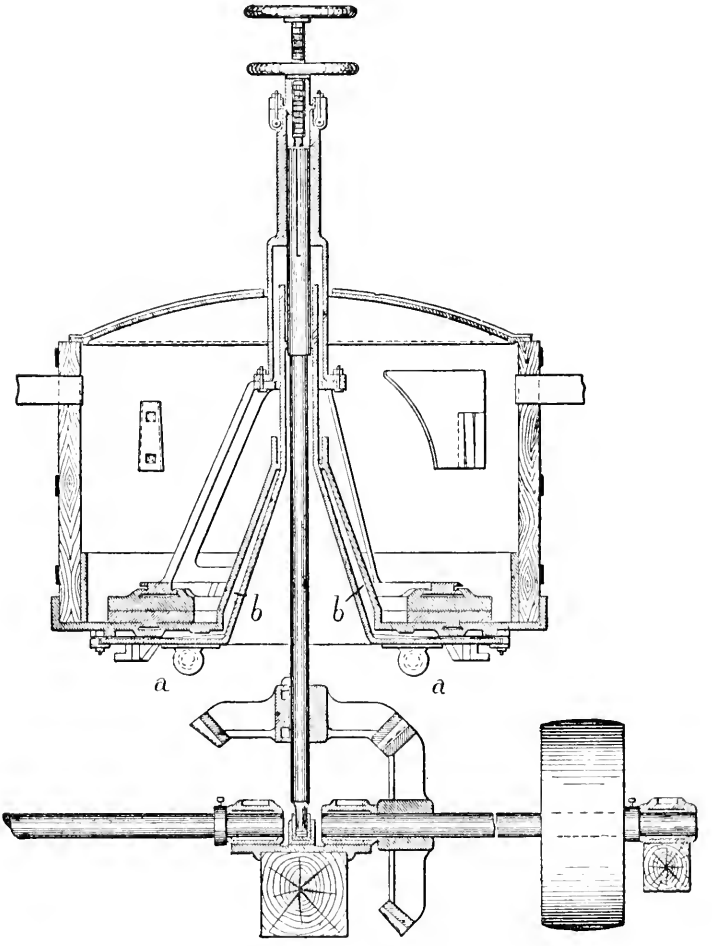


FIG. 271.—THE BOSS STANDARD AMALGAMATING PAN.

and screws of top of the spindle (*c*) so that the shoes and dies can be brought together when grinding, or be parted for circulation and mixing only. The spindle (*c*) is provided with a renewable steel toe, which is ground to a perfect fit and tempered. The step box (*d*) is bushed with brass, and loose tempered steel buttons are provided with the step box for the spindle toe to rest upon.

The mullers (*b*) are of various designs calculated to promote the most rapid circulation and intermixture of the pulp, one of which is shown in fig. 253. In some districts copper plates are introduced into the pan, and much of the amalgam is found attached to these, but the most usual system is to employ settlers entirely for the collection of the quicksilver and amalgam after the pans are discharged, which is effected through the pipe (*e*). Generally one settler is used for each two pans.

While the pulp is being worked in the pans steam is introduced to heat the mass and promote chemical reactions. Sometimes a steam bottom is used, as in the Boss standard pan (fig. 271). In other cases it is introduced direct into the pulp. The steam enters by the pipes (*a a*) and circulates in the chamber (*b b*).

The pans are driven by means of gearing and belting, as shown, but in the most modern mills, as in fig. 257, they are mounted direct over the main engine shaft, to which they are connected by means of friction wheels.

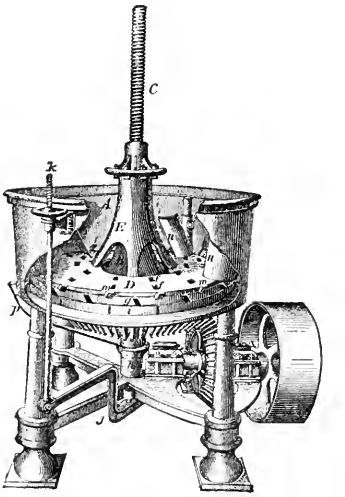


Fig. 272.
The Wheeler Amalgamating Pan.

In the Boss standard pan (fig. 271) projecting ledges are fixed to the inner side of the pan, which break up the pulp current as it swirls around, and force it towards the centre again.

Another well-known type of pan is the Wheeler, shown in fig. 272, which is about 4 ft. in diameter at the bottom, and 2 ft. or a little more in depth.

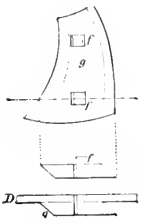


Fig. 273.
Shoe for the Wheeler Pan.

A is the rim of the pan, in the centre of which is the hollow cone (B) rising from the bottom, with which it is cast in one piece. Through this cone the vertical shaft (C) passes, which being driven by the gearing below the pan gives motion to the muller (D) by means of the driver (E) which is keyed to the shaft (C). The muller is provided on the under side with shoes (G) that form the upper grinding surface. The form of the shoes is shown in fig. 273. They are attached to the muller by means of two lugs or projections (*ff*) which are received in corresponding apertures in the muller plate, and securely wedged with pieces of wood. The lower grinding surface is formed by the dies (I) which are usually four or eight in number, covering the greater portion of the pan bottom, and secured to it in a manner similar to

that by which the shoes are fixed to the muller. There is a radial slot or space between the dies, which is commonly filled with hard wood. Below the bottom is a steam chamber for heating the pulp.

The vertical shaft or spindle (*e*) rests in a step box (*h*) to which oil is conveyed by the pipe (*p*). A vertical pin passes downward through the centre of the step box, in contact with the shaft, and resting its lower end on the lever (J). This lever may be raised or lowered slightly by the hand-wheel (K) thus raising the muller from the dies if required. The shaft (*e*) is also furnished with a screw, by means of which the muller may be raised up entirely above the rim of the pan for the purpose of cleaning up or changing the shoes and dies. The hoisting apparatus required in the absence of this screw is thus avoided.

In order to give an upward current or movement to the pulp, there are inclined ledges (*l*) on the rim of the pan, and smaller ledges (*m*) on the periphery of the muller, but inclined in the opposite direction. The pan is also provided with rings or guide plates (*n*) four in number, which serve to direct the moving pulp toward the centre. They are fitted into, and may be removed at pleasure from a T-shaped projection on the rim of the pan. The muller usually revolves at a speed of 60 revolutions per minute, and the pans require from $2\frac{1}{2}$ to 3 horse-power. Its ordinary charge in from 800 to 1000 lb., but in some mills larger charges are worked; the treatment of a charge requires about 4 hours. The shoes and dies usually wear out in from 4 to 6 weeks. Mill-men generally prefer a shoe of moderate rather than that of excessive hardness. The former wear out faster, but are thought to grind more efficiently. They are usually cast of an equal mixture, of white and soft iron.

The principal other pans are those known as Greeley's, Hepburn and Peterson's, Wheeler and Randall's, McCone's, the Combination pan, Fountain's pan, and Horn pan.

Settlers.—The pulp, after being ground and mixed with mercury in the amalgamating pan, is next led into settlers, in which it is thinned by the addition of water, and the quicksilver and amalgam is separated by setting from the sterile sand.

As with the pans there are numerous forms of settlers, but the most improved type is shown in fig. 254 (page 386). The pan is made of wood with a cast iron bottom, and is of an inside diameter of 8 ft. A complete circular muller plate is attached to the upright. spindle, and adjusted by the hand-wheels, as in the case of the pans. The muller plate is fitted with wooden shoes, and the whole weight of the muller and driver is carried by the upright driving spindle, which is supported by a step bearing on a steel button, the step

bearing being mounted on a cast iron plate resting on the cross timber of the pan framing. The weight of an 8-ft. settler, as shown, complete with staves and bands, is 7500 lb. Smaller sizes can be obtained.

Inside the staves around the bottom a groove is cast, starting from nothing on one side and gradually deepening to the syphon tap (*a*) on the opposite side, in which all the quicksilver is carried to the outlet. The pulp is drained off from the series of holes at successive intervals, the point of discharge being lowered by removing the plug from the next hole. There is no grinding action in the settler. All that is required is that the pulp shall be kept in gentle motion so as to allow the amalgam and quicksilver to settle. The muller revolves at the rate of about 15 revolutions per minute.

Agitators.—The pulp as it leaves the settlers, may still contain globules of amalgam or quicksilver, or the sulphides may be worth saving. In these cases it is usual to place an agitator (fig. 274) below the settler, so that any fine particles may be saved. The machine consists essentially of a wooden tub from 6 ft. to 12 ft. diameter and from 2 ft. to 6 ft. deep, in which the stirring arms, of which there are four, carrying vertical staves, slowly revolve. The stuff that accumulates at the bottom is shovelled out from time to time, and re-treated in one of the amalgamating pans.

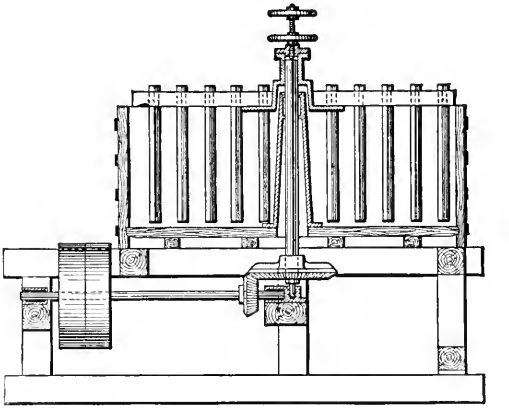


Fig. 274.—The Agitator.

Agitators, however, are not now generally used, and if there is any value left in the tailings, it is usual to put up more perfect concentrating appliances in order to recover it.

Clean-up Pans.—In these the amalgam from a gold and silver mill, when dirty and impure, is worked with additional quicksilver, and the waste matter washed off before retorting.

The Knox clean-up pan is 4 ft. diameter; wooden shoes are attached to the arms, and they are adjusted by means of the hand-wheels on top of the driving spindle, to bear on the bottom of the pan, or not, as desired, the motion being communicated through the bevel gear underneath to the spindle.

Fig. 255 (page 387), is a clean-up pan 3 ft. diameter, for the smaller silver

and gold mills, wherein there are no wooden shoes; but a very heavy bottom and muller admit of the iron surfaces coming in contact, which is especially valuable in gold mills for working up small quantities of concentrates from blankets and sluices, when these particles need brightening or polishing, that they may be taken up by the quicksilver. Clean-up pans of both sizes are also made with removable grinding faces.

In fig. 255 a cone pulley (3-step pulley) is shown on the countershaft, which admits of varying the speed of the muller. These are supplied when desired.

1 4-ft. clean-up pan	weighs	.....	3000 lb.
1 3-ft. ,,	,,	.....	2000 lb.
1 30-in. ,,	,,	.....	1500 lb.

The best makers construct the whole of the various machines, pans, settlers, etc., in sections, suitable for transportation in mountainous districts on mule-back, the pieces being of a weight not exceeding 300 lb.

I am well aware that a great variety of machines have been invented for the purpose of amalgamation; but as most of them have not got beyond the experimental stage, and none have come into extended use, I have confined my description to the well-known and well-tried appliances which have given excellent results throughout the mining world.

Mercury.—As may be naturally expected, there is a considerable loss of mercury in all processes entailing amalgamation. With ordinary free milling ores the usual loss which may be expected is one-sixth of an ounce of mercury for each ton of ore milled. In a 10-stamp mill the loss of quicksilver per ton of ore will be from one-sixth to one-third, or say 12 lb. to 15 lb. per month. The amalgam is retorted about once in every fifteen days, and the distilled mercury is returned to the battery again minus the loss mentioned above. In a 10-stamp mill it is advisable to have two tankards of mercury in reserve, one for use in the batteries and one for the amalgam pan. A mill of, say, 80 stamps, running an ore of a value of 30*s.* to £2 per ton ($8 to $10), only six tankards, or 460 lb., would be required in reserve. The ordinary amalgam pan requires about 200 lb. of mercury to run it properly. Fine gold requires a proportionately larger quantity of mercury for amalgamation than coarse, and the loss is a little greater. Greater losses occur on partly refractory ores, and the mercury must in all cases be handled with great care, or the losses will much exceed the estimate.

For a 10-stamp silver mill the stock of mercury should be large to begin with. In a dry crushing silver mill the loss is usually from $\frac{1}{2}$ to $\frac{3}{4}$ lb. per ton of ore. Ten-stamp mills usually require from 200 to 250 lb. of mercury per month to make up for loss, or say three flasks. The stock which should be kept in hand will depend upon the richness of

the ore, but would be about 1500 lb. in the pans, 1500 in the settlers and in circulation, and at times 1500 lb. locked up in amalgam, so that a stock of from 2 to 3 tons would be required to start with.

As a rule, in dry crushing silver mills, little or no chemicals are used in the pans, with the exception of occasional borings of iron or zinc, amounting to 8 lb. to 10 lb. per ton. The chemicals given in the list on page 374 would in most cases answer for a dry crushing silver mill also.

CHAPTER XXIII.

DRYING AND ROASTING MACHINERY.

Ore Drying and Roasting Machinery—Drying Floors—Drying Cylinders – Shelf Drying Kiln—Roasting—Reverberatory Furnace—Brückner Roasting Cylinder—Improved Brückner Roasting Cylinder—The Howell Improved White Roasting Cylinder—The Stetefeldt Roasting Furnace—The O'Hara Roasting and Chlorodising Furnace—The Argall Roaster—Argall Cooler.

Ore Drying Machinery.—It is absolutely necessary that before the ore is sent to the stamps for dry crushing it shall be perfectly dry itself. The old method of drying the ore was to spread it upon a flooring of iron plates, underneath which there was a labyrinth of flues. This method, however, is not economical, and entails much handling of the ore. The modern method is to dry the ore in a revolving iron cylinder, such as that shown in fig. 275, and which, in the mill, is situated in the position shown at *g* in fig. 260, between the ore bin and the stamps. The cylinder is of cast iron, made in several sections for convenience of handling, and having two tyres on which it rotates, supported by rollers underneath.

The rotating motion is transmitted to the cylinder through the spur-gearing and belting shown. The cylinder is slightly conical in shape, being as a rule 36 in. diameter at the smaller end, into which the ore is fed, 18 ft. long, and 44 in. diameter at the larger end nearest the furnace. Its total weight is about 19,000 lb., and its capacity from 30 to 40 tons per 24 hours.

The iron cylinder is lined with firebricks, for which purpose about 1100 are required, and it should be connected to a chimney of about 40 ft. high.

The axis of the cylinder is placed horizontally; but, owing to its conical form, the ore must travel gradually from the smaller towards the larger end, where the furnace is placed. Shelves or wings are arranged spirally inside the cylinder, and raise the ore and shower it through the flames, thus assisting to quickly and thoroughly dry it. The dried ore drops into a pit, from which it is drawn through a cast iron door, and by means of sheet iron chutes is conveyed to the automatic feeders and so on to the stamps.

The ore may also be dried on a "shelf dry kiln," which consists of

a series of inclined iron shelves arranged in a kiln in such a fashion that the ore will slide downwards from one to another, being at the same time exposed to the action of the heated gases ascending from the furnace below. The process is economical, and requires no motive power and produces no dust. Mr. Argall, of Denver, U.S.A., has invented an improved ore dryer which is in extensive use in Colorado. The form of this is shown in fig. 283 (page 433), and the cost of drying from six per cent. moisture to one per cent. is approximataly $\frac{1}{2}d.$ per ton.

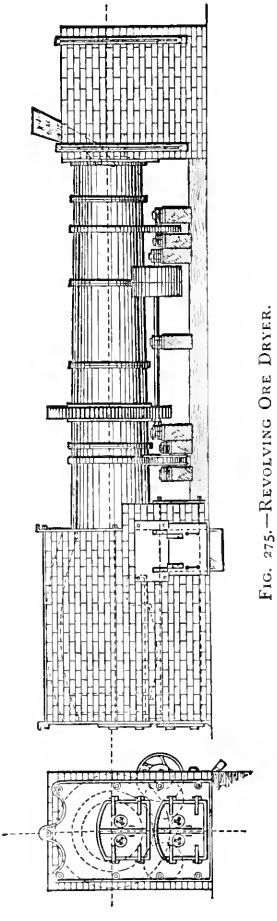


Fig. 275.—Revolving Ore Dryer.

Roasting.—Many of the ores of gold and silver contain the precious metals so securely locked up that they cannot be freed by the mechanical action of pulverisation for the succeeding processes of amalgamation, lixiviation, or chlorination. Chemical means must therefore be resorted to, and the operation usually adopted is to roast the ores in suitable kilns or furnaces, with a view either to convert the metal in the ore to the state of oxide (called oxidising roasting), to the state of sulphate, or lastly, to that of a chloride (called chlorodising roasting), according to the ore and the treatment to be afterwards carried out for the recovery of the precious metals. The subject is an intricate one, and necessitates considerable chemical knowledge for its successful manipulation; and I would refer my readers to the two treatises of Mr. Eissler,* in which they will find full details of the practical working of many of the numerous roasting furnaces.

The ore is roasted either in the mass as it comes from the mines, in which case it is treated in heaps, stalls, or kilns, or after it has been crushed, with or without concentration, in the mill.

As we have now to deal more especially with the machinery employed to effect the operation, it is with the latter class of ore with which we have to deal, and must go back for a moment to the crushing or pulverising machinery. Now, the most suitable condition of the powdered ore or pulp for roasting is when the ore particles are finer than those

* "The Metallurgy of Gold" (Fifth edition), by M. Eissler; and the "Metallurgy of Silver" (Fourth edition), by the same Author. London: Crosby Lockwood & Son.

of the gangue. When the crushing is accomplished by means of rollers, the grains or particles of ore and gangue are of a more even size, which, though of considerable advantage for concentration, is not so much so for roasting. The reverse, however, appears to be the case when the

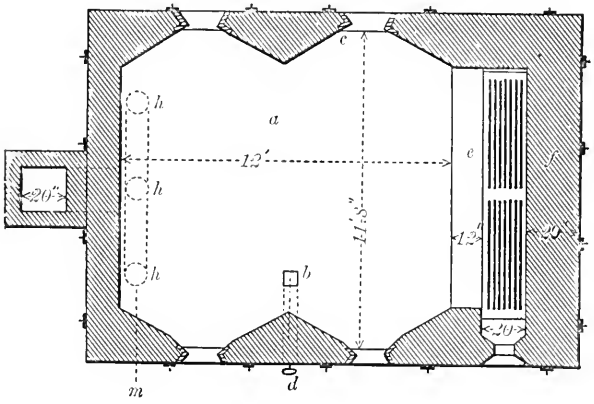


FIG. 276.—PLAN OF REVERBERATORY ROASTING FURNACE.

mineral has been stamped; for in stamping, owing to the greater specific gravity of the ore particles, they cannot so easily evade the blows of the stamp and remain longer exposed to their action than the lighter gangue, and are consequently reduced to a finer state. The ore particles,

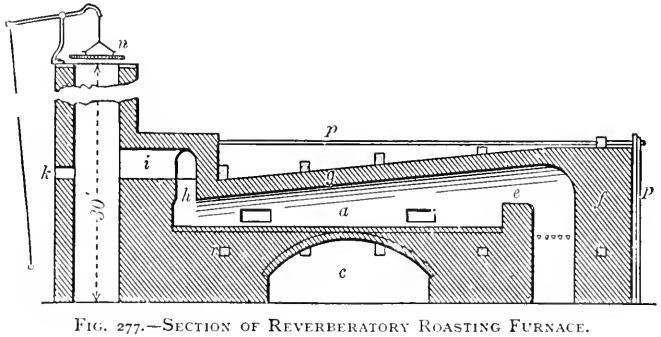


FIG. 277.—SECTION OF REVERBERATORY ROASTING FURNACE.

therefore, are reduced to a finer grade than those of the gangue, and thus the mineral is in the most suitable condition for roasting.

The appliances used for the roasting operation may be either reverberatory furnaces and kilns built of brick, as in figs. 276, 277, or a variety of revolving roasting cylinders, or furnaces, built on the Stetefeldt or O'Hara principles.

The furnace shown in fig. 276 is given for the sake of comparison

with the mechanical roasters, and may be either single or double, as the one illustrated in the small chlorination mill (fig. 286).

Reverberatory Furnace.—The small single furnace shown in plan and section in figs. 276 and 277 will treat one ton of sulphides at a charge

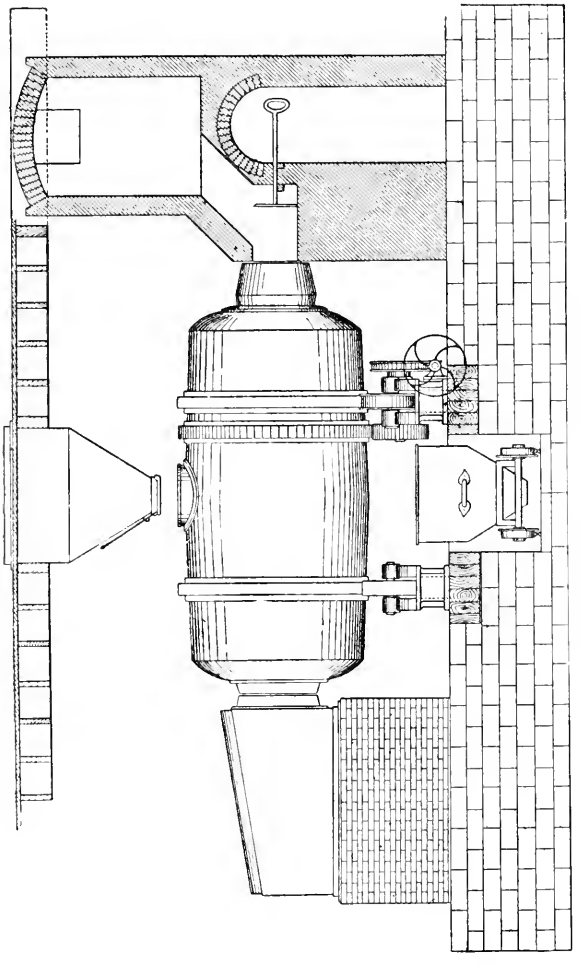


FIG. 278.—BRÜCKNER ROASTING CYLINDER.

upon the hearth-bottom (*a*). It is fed in through a hole in the arched roof (*g*) and spread out in a thin layer upon the hearth, where it is exposed to the action of the heat and gases from the furnace, and at the end of the operation, during which it is raked over and stirred by hand through the side openings, it is discharged through the square opening (*b*) in the floor into the pit (*c*) and is then removed to the cooling floor to

await the next process. The bridge (*e*) is from 10 in. to 12 in. wide and from 8 in to 10 in. high, and should be made of some refractory material, like firebricks. It separates the hearth from the fireplace. The outside walls should not be less than 24 in. thick. The roof should not be more than 20 in. from the bottom, and the whole construction should be well braced together by means of iron ties and wall-plates (*p*). The smoke and fumes pass away through the flues (*h* and *i*) into the chimney, on the top of which is a cover (*n*) by means of which the draught may be regulated.

Passing now to the mechanical arrangements by which roasting is accomplished in modern mills, of which indeed there are numerous varieties, we will notice a few only of those which have become most favourably known, and are generally adopted in gold and silver mills for the roasting of refractory ores.

The Brückner Roasting Cylinder, represented in fig. 278, is 6 ft. in diameter and 12 ft. long, revolves on four rollers, and is rotated by the spur gearing shown, which in turn is driven by the worm gear and pulley. The cylinder is of iron, lined throughout, both in the body and conical ends, with firebricks, of which a total number of 1300 will be required for this purpose, and for lining the iron firebox shown on the left. The hopper placed above the cylinder is sufficiently large to contain a charge which, for this machine, will be from 3 to 4 tons. Two receiving and discharging doors are provided midway in the length of the cylinder, and come directly under the hopper. They discharge into an iron hot ore car placed beneath, or, if desired, straight into the pit.

At one end is the furnace, and at the other the chimney. The conical ends revolve close against the openings, and the draught is regulated by means of the damper as shown.

The revolution of the cylinder causes the ore to be thrown backwards and forwards, and so, by changing its position, frequently exposes new surfaces and particles to the action of the fire.

The capacity largely depends upon the ores, some of which require but 4 or 5 hours to be thoroughly roasted and chlorodised, while others need as much as 12 hours, or longer.

The weight of the 12 ft. × 6 ft. cylinder is 15,000 lb., and its capacity 3 to 4 tons. The larger size, 7 ft. × 18 ft., capable of treating 6 to 8 tons at a batch, weighs 28,000 lb.

The Improved Brückner Roasting Cylinder, illustrated in fig. 279, is 7 ft. diameter × 18 ft. long, made of the best iron, and lined throughout with firebricks. It revolves on two chilled iron friction rings, resting on four chilled iron rollers. The rotation is caused by friction on the carrying rollers, which are driven by spur-gearing and pulleys.

The cylinder is provided with four receiving and discharging doors, in two pairs, placed opposite each other. The operation is the same

as in the cylinder previously described, and the weight, with iron trimmings for the brickwork, is 30,000 lb. With an iron smoke stack, base plate, and guys added, the weight is 31,500 lb.

The drawback to the Brückner cylinders just described is that they

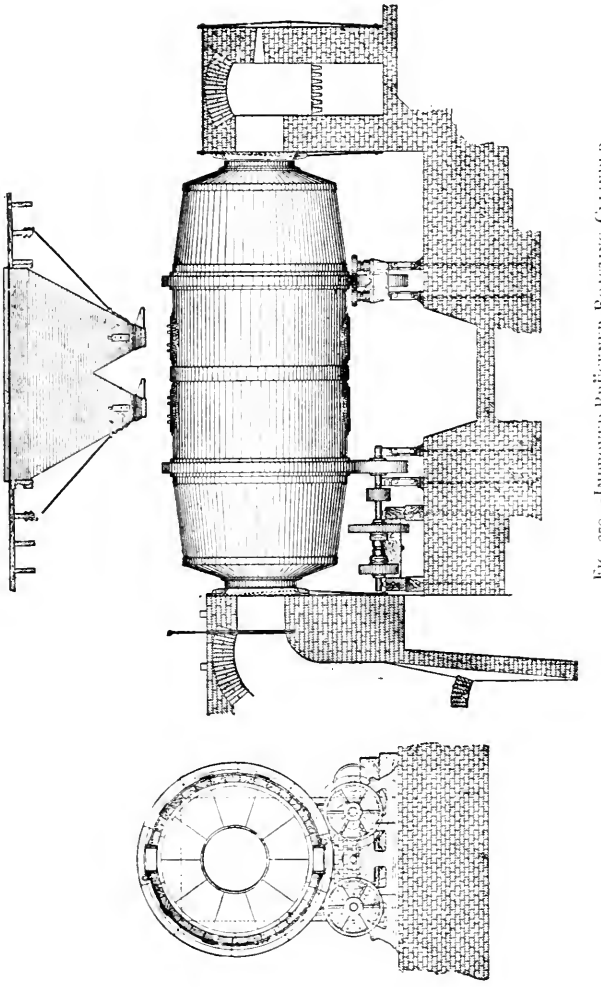


FIG. 279.—IMPROVED BRÜCKNER ROASTING CYLINDER.

are not continuous in their action, but deliver the ore in batches at considerable intervals. To obviate this difficulty the *White* roasting furnace has been invented, and improved upon again in the *Howell* Improved White Roasting Furnace.

The Howell Improved White Roasting Furnace consists of a long cast

iron revolving cylinder inclined towards the fireplace, in as shown fig. 280, and enlarged at the lower end, which alone is lined with firebrick, leaving the metal on the smaller portion exposed, as the greatest heat is at the fire end. It is supported on four wheels or rings, resting on truck wheels, and guided in a central position by rollers in upright frames, and is revolved by friction on the truck wheels, which are driven by means of gearing and pulleys. Inside the cylinder the ore is raised, and showered through the flames by means of cast iron spirally arranged shelves, which rotate with the cylinder.

The ore is fed through a hopper at the chimney end, and if salt is used for chlorodising it, is mixed with it before it enters the cylinder. It then slowly finds its way down the cylinder from the coolest to the

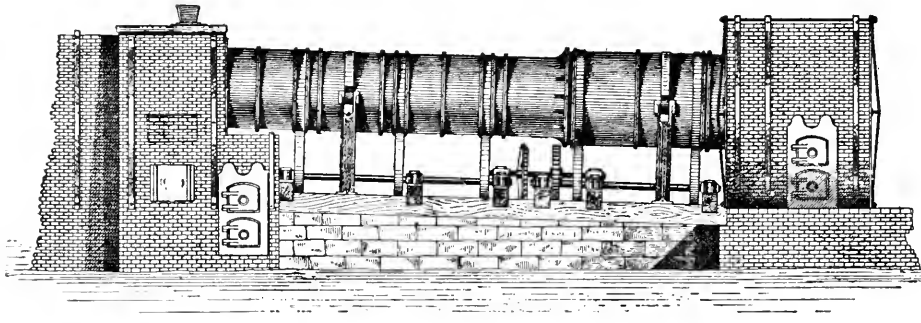


Fig. 280.—Howell Improved White Roasting Furnace.

hottest end, and finally drops into a pit at the lower end, whence it can be withdrawn as roasted pulp as required.

These furnaces are built in three sizes—

40 in. × 24 ft.	. . . .	capacity 15 to 20 tons.
52 ,, × 27 ,,	. . . .	,, 20 ,, 30 ,,
60 ,, × 27 ,,	. . . .	,, 30 ,, 45 ,,

The amount of firebrick required for lining the furnaces and 20 ft. of dust chamber is—

Size of Cylinder.	No. of Common Bricks.	Firebricks.
40 in. × 24 ft.	26,000	1900
52 ,, × 27 ,,	26,000	1900
60 ,, × 27 ,,	28,000	2700

Auxiliary furnaces for roasting the dust, which escapes from the main furnace, are sometimes used for both the White and the Howell improved White roasting furnaces but are now seldom employed.

The Stetefeldt Roasting Furnace.—In this furnace the ore is chlorodised and roasted while falling from the hopper (A), of fig. 281, down the shaft

(B), which is from 26 ft. to 46 ft. high, according to the refractory nature of the ore. The shaft (B) has a horizontal section of from 4 ft. to 6 ft. square, and is heated by the two fireplaces (G). In order to obtain perfect combustion of the gases when leaving the furnaces, they are supplied by means of the passages, or with a current of fresh air, regulated by dampers to the quantity necessary to obtain a perfect combustion of the gases.

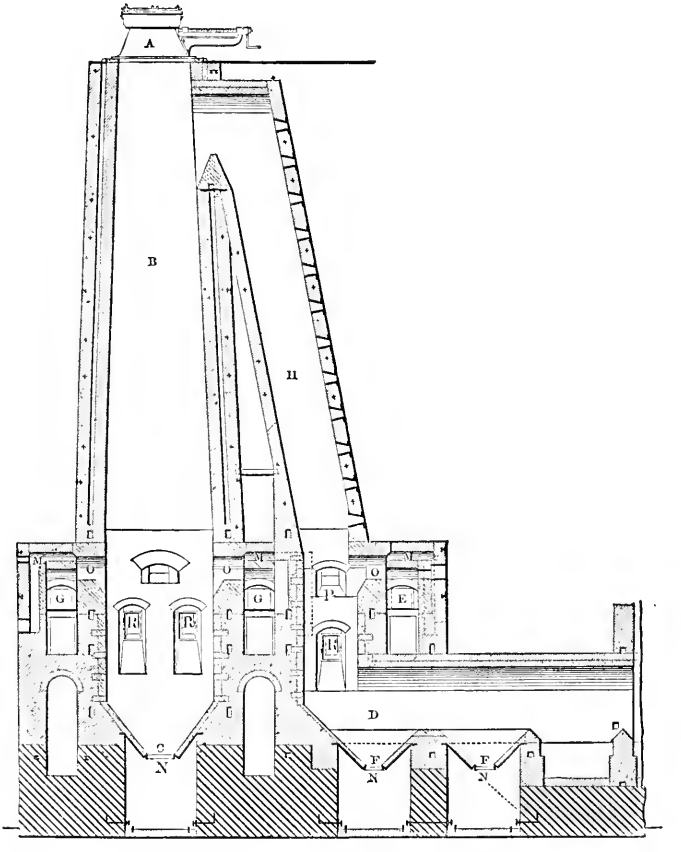


FIG. 281.—STETEFELDT ROASTING FURNACE.

The main shaft is built slightly tapering and is double, so that the air space between may keep the heat regular; it is connected at the top with the flue (H) in which the fine dust, which is carried over in considerable quantities by the strong draught, receives an additional roasting from the fireplace provided at E, and is finally deposited in the hoppers (F F) of the dust chamber (D). The water gases pass off through a chimney which is from 60 ft. to 100 ft. high and from 4 ft. to 5 ft. square.

The main body of the ore falls through the ascending current of gases in the shaft (B) into the hopper (C) from which it is withdrawn by special arrangements, while the various doors (R and Q) serve to admit air, and for examining and cleaning the interior, and the dust which settles on the sloping sides of H can be removed by the doors (S S).

The Stetefeldt furnace is made in three sizes, of which

No. 1 has a capacity of from 40 to 80 tons per 24 hours.
,, 2 ,, ,, 20 ,, 40 ,, ,,
,, 3 ,, ,, 10 ,, 20 ,, ,,

the capacity, however, varies much with the quality of the ore. The cost of roasting by this method is from 16*s.* to £1 per ton, though, in places where salt, fuel, and labour are expensive, it may run up to £1 16*s.* per ton.

The following is a list of the materials used in the construction of these furnaces :

	Iron Plant.	Stone.	Bricks.	Firebrick.
No. 1	48,000 lb.	3000 cubic ft.	260 M.	5000
,, 2	32,000 ,,	2500 ,,	200 ,,	3500
,, 3	25,000 ,,	2000 ,,	150 ,,	2500

The O'Hara Roasting and Chlorodising Furnace.—We have now seen how the roasting furnace has been developed from the original reverberatory hearth to the automatic and continuous processes of the Brückner and Stetefeldt furnaces, and the next mechanical arrangement which will be described is that known as the O'Hara, which consists of two long separate hearths, one above the other, over which the ore is drawn in a steady stream, being desulphurised on the upper, and chlorodised on its return journey across the lower, hearth. The whole arrangement is shown in fig. 282.

Attached to an endless chain, at proper distances apart, are iron frames formed into a triangular shape; on these frames are a number of ploughs or hoes set at an angle. One set turn the ore toward the centre, the next set turn it in an opposite direction toward the walls. These ploughs move through the ore every minute and expose a new surface of ore to the flames and gases.

The space between the roof and hearth of each compartment is quite small, so as to confine the heat close to the ore.

The operation of this furnace is as follows : The ore is fed continually from the battery into the hopper, through which it then falls on the upper hearth. The ploughs, actuated by the endless chain, stir the ore over and over on the hearth and move it gradually to the opening where it falls to the lower hearth. As the ore is passed along in the upper compartment it is thoroughly desulphurised by the heat furnished by the fires as described, and by the combustion of the sulphur in the ore.

This action is assisted by the oxygen in the supply as admitted at intervals through the sides of the furnace by the openings,—for a chloridising roasting salt is mixed with the ore as it is fed into the hopper, and becomes thoroughly intermingled with it by the stirring action of the ploughs. If there is any free silver in the ore it gets the benefit of the chlorine vapours passing up from the lower hearth.

When the ore falls through the opening and on to the lower hearth, the fall breaks any spongy lumps or masses that may have been formed, and the ore is again stirred over and over, and moved along through the flame and gases over the lower hearth by the action of the ploughs towards the discharge opening.

The ore has become gradually more and more heated in its passage through the upper hearth, and by the time the extra heat is required as stated it comes immediately in front of the same fires which have, during the whole process, furnished the heat.

Ordinarily the ore will be from 5 to 10 hours in passing through the furnace—according to its character. Only one man is required to attend the fires, no other attention being necessary, as the ore may be fed to the furnace by mechanical means, and discharged from the furnace in a car, conveyer, or elevator, and discharged in hoppers over the pans.

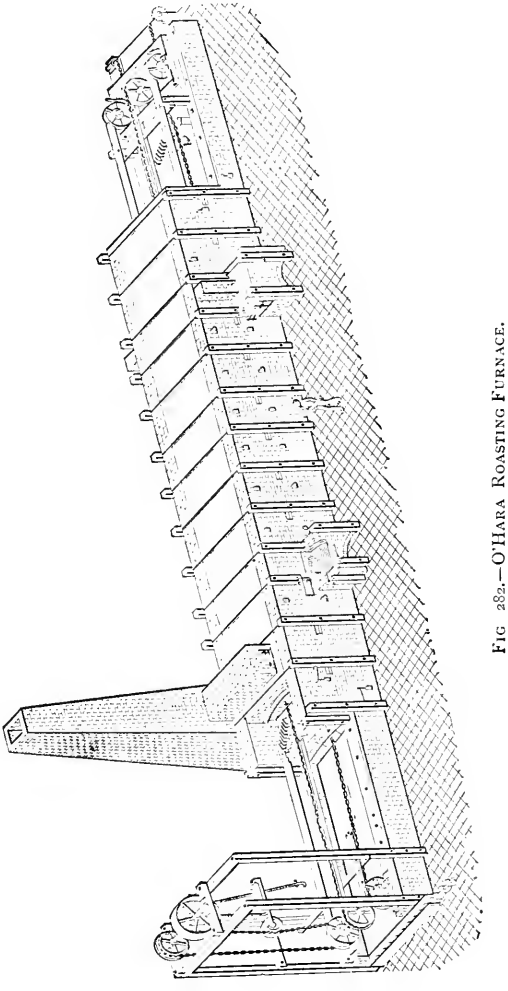


Fig 282.—O'Hara Roasting Furnace.

The materials required for the construction of an O'Hara furnace are—

METAL.

Bolts	1,100 lb.
Wrought iron	6,600 ,,
Cast iron	3,125 ,,
Total	10,825 lb.

BRICK AND STONE.

Furnace	137,000
Stack 80 ft. high, 7 ft. × 7 ft. base, 2 ft. × 2 ft. flue, built hollow walls	75,000
Total	212,000

Stones, 125 cubic yds.; firebricks, 100 cubic yds. or more; length of hearth, 60 ft.; two cooling hearths, each 30 ft. = 60 ft., total 120 ft.; width of hearth, 8 ft.; ditto over all, 14 ft.; height over all, 14 ft. Will work up to 50 tons. Burns 3 to $3\frac{1}{2}$ cords of wood per day. The top of the furnace may be covered with cast iron plates, making a first-class drying floor. It is continuous in its working. A furnace of smaller dimensions for working 20 tons will cost somewhat less.

The Argall Roaster.—In the ordinary type of cylindrical roaster, such as the Brückner, the full weight of the ore is continually being lifted up as the machine revolves, and requires a considerable expenditure of power. Mr. Phillip Argall, of Denver, U.S.A., has designed a roasting furnace which quite overcomes this difficulty, by using four tubes instead of one by which means the weight of the ore is distributed and balanced at all points of rotation. As a consequence very little power is required beyond that necessary to overcome the friction of the machine. This machine, which is also arranged as a dryer, is shown in fig. 283, as installed at works in the Cripple Creek district, Colorado.

The four tubes are made of plate steel, and all the seams are butt and strap jointed, the rivets being driven flat on the inside so as to facilitate the introduction of the fire-clay tile lining of the tubes, which are nested inside two cast steel track bands. At the upper end there is a cylindrical inlet shell which receives the raw ore and distributes it in thin layers into the four tubes. The ore is thus brought into close contact with the flames, and is thoroughly and evenly roasted at a minimum expenditure of fuel. The furnace supplying heat to the roaster runs on rails, as shown at the lower end, the fire-box being portable with an underfeed stoker. The air chamber supplying the blast to the stoker is below the floor level.

The two track bands rest on four rollers, which are driven by means of the compensating gear mechanism shown in fig. 283A, thus equalising any differences in the diameter of the tract bands or conveying rollers. In the old form of rotary furnace the uneven wear of one set of rollers

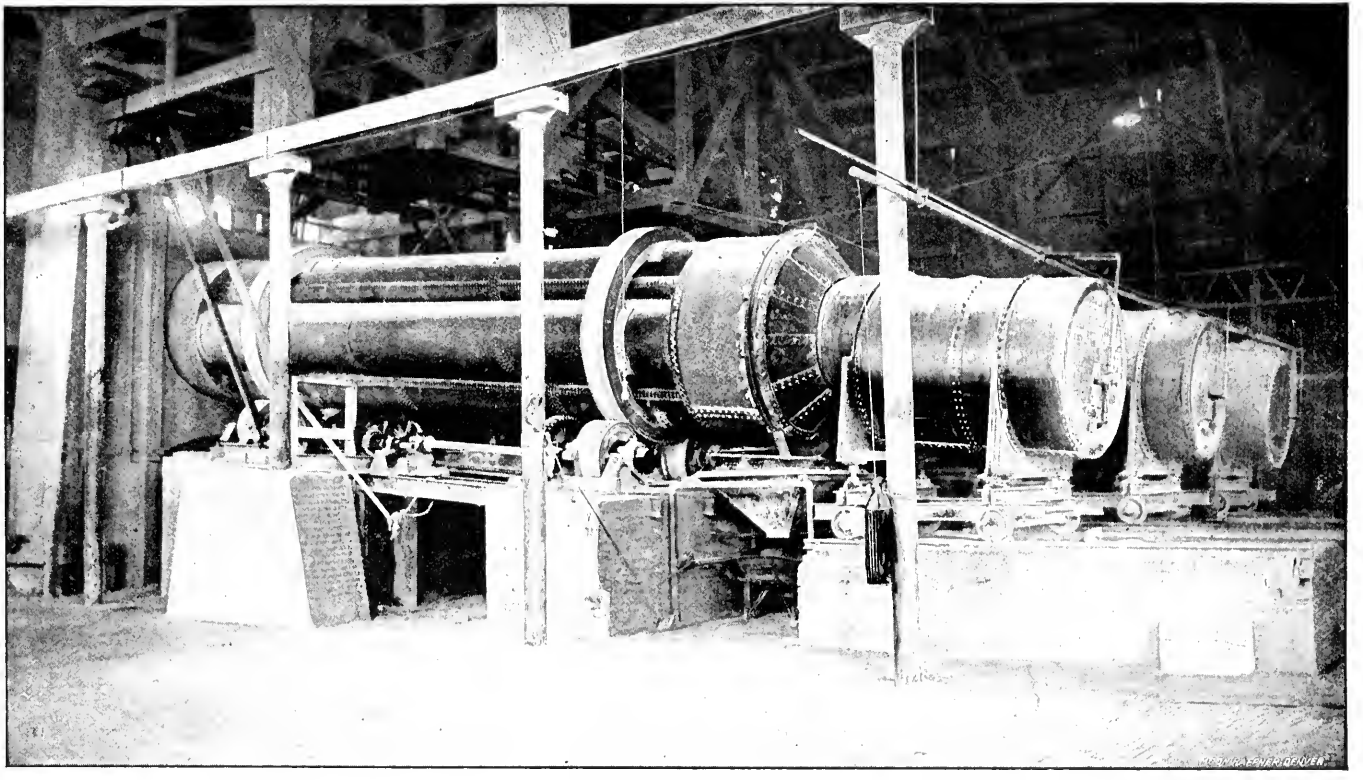


Fig. 283.—Argall Roaster.

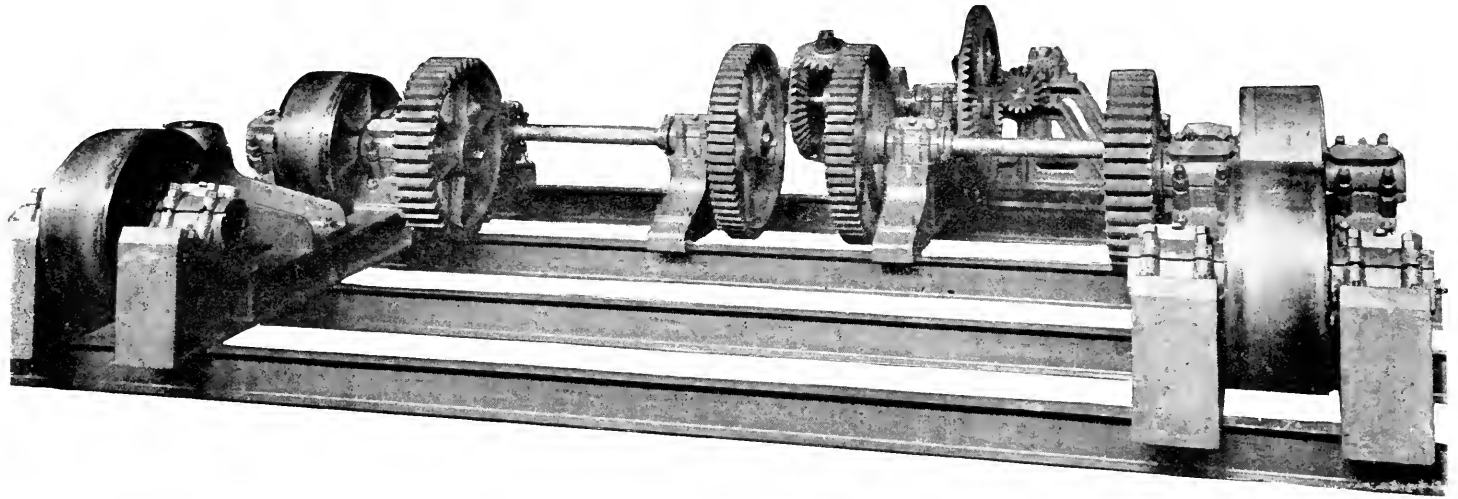


FIG. 283A.—COMPENSATING GEAR OF THE ARGALL ROASTER.

or bands, is a constant source of expense, besides causing the one set to pull against the other, greatly increasing the power required for driving.

On account of the small diameter of the tubes, and their slow, steady motion, the flue dust is reduced to a minimum; while the high terminal heat only possible in this form of a mechanical roaster thoroughly breaks up the sulphides, and gives the much-desired dead roast so essential to successful chlorination and cyaniding. The following are the general details of this machine:—

Roasting furnace complete ironwork only	63,600 lb.
Fire tile lining required	14 tons.
Approximate firebrick required	5,000 ,,
,, red brick ,,	20,000 ,,

If the foundations piers of the roaster and firebox are built of stone, then 10,000 red brick will suffice. The capacity for 24 hours' treating Cripple Creek ores and reducing the sulphur from 2 per cent. to 0·10 per cent. is from 45 to 50 tons, while the horse-power required is only one. The necessary floor space is 756 square ft.

The Argall dryer is a modification of the roaster for the special purpose of drying ore, and does not require a special description.

The Argall Rotary Ore Cooler.—As the roasted ore leaves the furnace at a temperature of over 1000° Fahr., it is evident that it cannot at once be submitted to the cyanide or other leaching process without being cooled down. In order to do this quickly, Mr. Argall has invented a rotary ore cooler of the type shown in fig. 284.

The shell consists of an outer and inner main-tube. Water is circulated in the annular space between these tubes, and in addition to this there is an independent set of boiler flues inside of the main inner tube, which also have a water circulation of their own. The ore to be cooled is fed at one end and as the cooler revolves gradually travels downward. towards the discharge end, where it is delivered, by means of a series of small cast iron doors, shown in the illustration, either to a car or hopper, or to such other conveying mechanism as may be provided in each particular case.

The cold water is admitted at the discharge end of the cooler and flows towards the feed end, being finally returned in four pipes to the discharge end, but above and out of the way of the ore. The discharge end of the cooler is therefore as cool as the in-coming water, while the feed end is subjected to the heat of the ore bearing from 800° to 1000° Fahr. The unequal expansion must therefore be seen to, which is done by inserting a Morrison corrugated flue in the inner shell. The inner boiler tubes with their heads are also free to expand independently.

The shell is provided with a suitable number of hand holes, and all

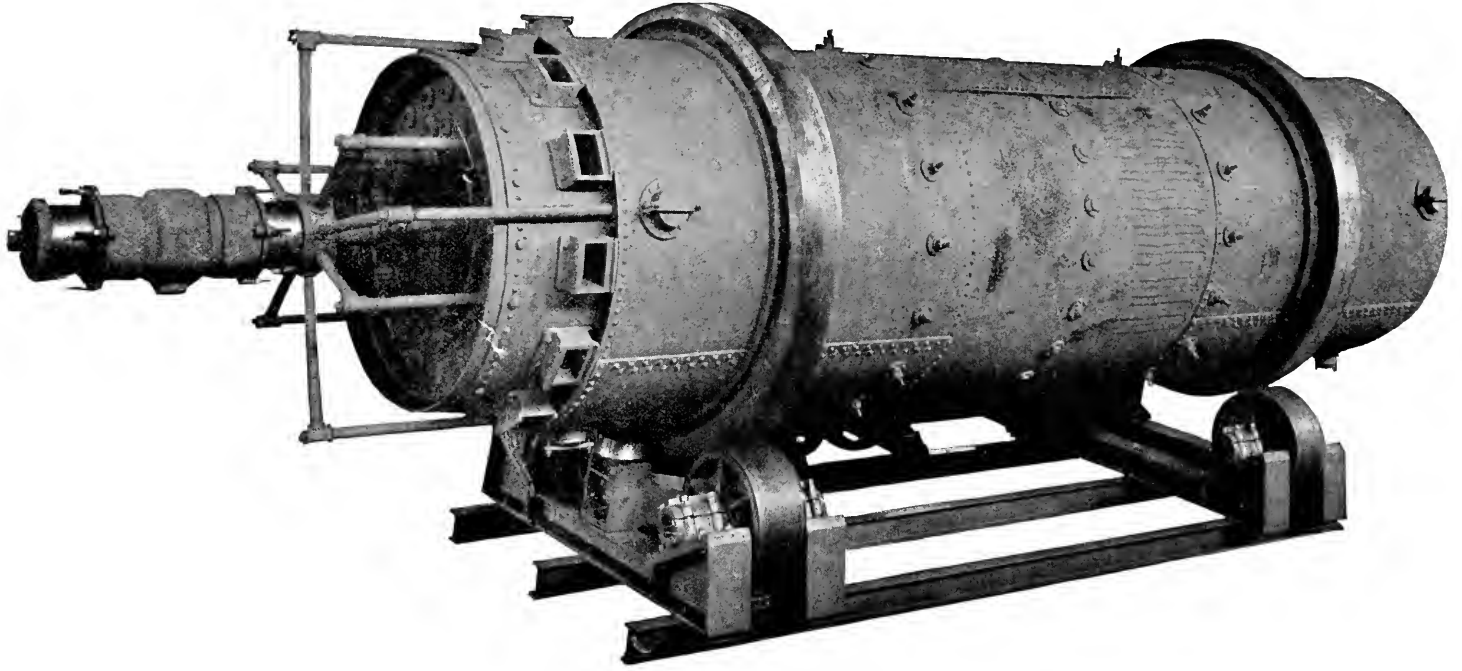


Fig. 284.—Argall Rotary Ore Cooler.

tubes are so arranged as to be accessible and easy to replace in case of repairs.

The track bands are made of the best quality of open hearth steel castings, turned true on the outside, and supported by the carrying truck wheels, which are made of a special mixture of very hard iron.

The carrying frame is of iron and steel construction throughout, and the driving mechanism, having an equalising gear, partakes of the same advantages as the driving mechanism supplied for the Argall dryer and roaster.

The advantages of a cooler of this kind over the old-fashioned cooling floor are very obvious. It is continuous in its action, requires but very little room in comparison with that of a large cooling floor, and dispenses with all of the hand-labour necessary for spreading the material over a large flat area. The capacity of the machine is about 300 tons per 24 hours, and its total shipping weight approximately 37,000 lb.

I had an opportunity in October, 1900, of visiting the works of the Metallic Extraction Company, of Cyanide, near Florence, Colorado, U.S.A., where I saw the Argall dryers, roasters, and coolers in full work, and there is no doubt but that these machines carry out very successfully and economically the various processes for which they are designed. For a fuller description of these machines as well as of the Argall high-speed rolls, I would refer my readers to a paper written by Mr. Argall, and in his absence read by myself, before the Institution of Mining and Metallurgy, London, on February 20th, 1902.

CHAPTER XXIV.

THE CHLORINATION AND CYANIDE PROCESSES FOR THE EXTRACTION OF GOLD

General Outlines of the Chlorination Process—Description of Providence Mill, Colorado —The Newbery-Vautin Process—The Cyanide Process.

GOLD is extracted from refractory ores by two processes, either by chlorination, or else by the use of cyanide of potassium.

The Chlorination Process.—This consists first in roasting the ore, as described on page 422, and then in the conversion of the gold particles into terchloride of gold. The process may be described * in general terms as follows:

(1) The auriferous concentrates from the stamping mill, having been perfectly oxidised by roasting, are moistened with water and put lightly by means of a sieve into a wooden vat coated with tar and rosin, having a perforated false bottom, upon which a filter is made, for which there are numerous ways. When fitted, a close-fitting cover is placed on the top.

(2) Chlorine gas, produced by decomposing salt and peroxide of manganese with sulphuric acid, is introduced between the false and true bottoms, and made to permeate upwards through the ore mass. After the expiration of from 15 to 48 hours, the gas is found to appear abundantly on the ore mass, and is then shut off, and the vat allowed to remain a few hours under the influence of the gas. The cover being removed, pure water is added to fill the vat even with the top surface of the ore. The fine particles of gold, under the action of chlorine, have changed from metal to a soluble terchloride, and in this condition it is drawn off or leached out with water, fresh water being added until a test shows no trace of gold.

(3) A prepared solution of sulphate of iron—the usual precipitant—is carefully added to this drawn-off solution, and the gold thrown down as a black or brownish precipitate. This is gathered, washed, and melted into ingots of nearly pure gold.

* "Treatise on the Concentration of all Kinds of Ore, including the Chlorination Process," by the late Professor Küstel. (San Francisco, 1868.)

The conditions just mentioned are carried out in practice by a simple arrangements of vats (as shown in fig. 285, which illustrates the chlorination mill at the Providence Mine, Grass Valley District, Colorado), and the process is as follows :

"The ore treated is quartz, carrying free gold, pyrites, galena, chalcopyrite, arsenopyrite, and zinc blende. It is first crushed in rock-breakers, and then stamped fine enough to pass through a 40-mesh sieve. Then it passes as a slime over silver-plated copper amalgamating plates to Frue concentrators. The free gold is caught in the stamp batteries and on the plates ; the sulphides are collected by the concentrators. The latter are dried and then roasted, chlorinated, and leached. The roasting is done in a three-story reverberatory

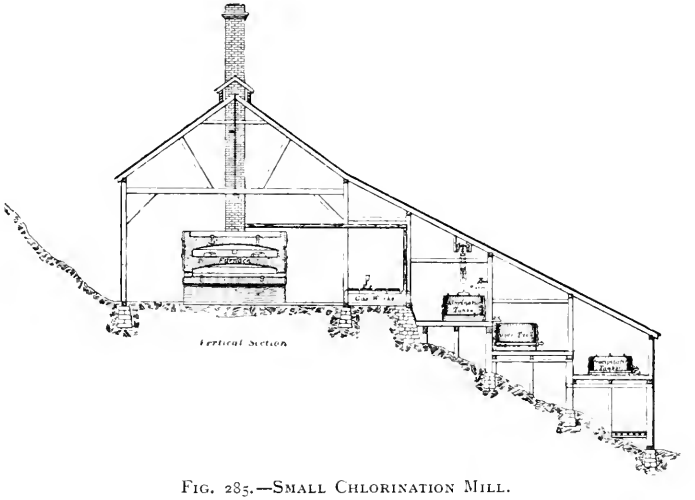


FIG. 285.—SMALL CHLORINATION MILL.

furnace. About one per cent. of salt is added near the close of the operation. All the sulphur, arsenic, and antimony are expelled, and the iron and other base metals oxydised. The gold is left in a free metallic state, the silver being partly concentrated into a chloride by the salt.

"The roasted ore is then transferred to chlorinating tubs, holding from 2 to 3 tons each. The covers are put on, and the joint caulked with rags and luted with dough to make it gas-tight. The tubs have false bottoms, full of holes and covered with sacking. Chlorine gas, made from salt, black oxide of mangenese, and sulphuric acid, is then introduced below the false bottom and allowed to permeate the ore. Two or three days are required for their permeation. The gold and silver is thus concentrated into chlorides. The chloride of gold is leached out by water added at the top and drawn off at

the bottom, and run into precipitating tanks. The gold is precipitated in a fine metallic state by the addition of sulphate of iron. The water is then run off, the gold collected and dried, melted in graphite crucibles, and cast in bars.

"The silver chloride remaining in the ore is dissolved out by a solution of hyposulphite of soda. The solution is run into other tanks, and the silver precipitated as a sulphide by adding calcium polysulphide. The sulphide of silver is dried, roasted, and then melted and cast into bars. The cost of milling and treating the sulphides is $1·37 per ton of ore."

The simplicity of the above arrangement involves, however, the handling of the ore several times in order to fill and empty the vats.

The Newbery-Vautin Chlorination Process.—Many attempts have been made to improve upon the simple chlorination plant already described, and perhaps that known as the "Newbery-Vautin" is the one which hitherto has been the most successful from a commercial point of view, and has given most satisfactory results, notably at the Great Mount Morgan Mine in Queensland, and elsewhere.

The plant required for the chlorination of the ores after roasting is simple in its construction, requires but little power, and its working will be understood by reference to fig. 286.

The processes already described having been gone through, the roasted ore—which should be crushed to such a state as to pass through a 30-mesh sieve—is delivered into the chlorinating mill by the truck (B) on the tramway (A) and discharged through the hopper (C) into the chlorinating barrel (E). Five to 10 per cent. of water is then added, with 1 per cent. of chloride of lime and the same quantity of a special reagent; the cover is then secured and the chlorination set in motion, until the gold is transformed into chloride of gold and has been dissolved.

The solution of gold is then removed, either by upward or downward leaching—which can be effected by gravitation or the use of a pump—into the tank (H) and then from there by the pump (F) into the tank (I); or, in order to facilitate the leaching, the pipe connected with the chlorinator can be connected direct with the pump. Another method of filtration is by admitting water under pressure at the top of the chlorinator when closed, and forcing the solution through the filtering medium contained in the bottom of the vessel and into the tank (H) from which it can be pumped up into the tank (I).

The solution in the tank (I) which contains the gold in the state of chloride, is allowed to run by gravitation through the precipitating vessels (K) where the chloride is decomposed and the metallic gold deposited.

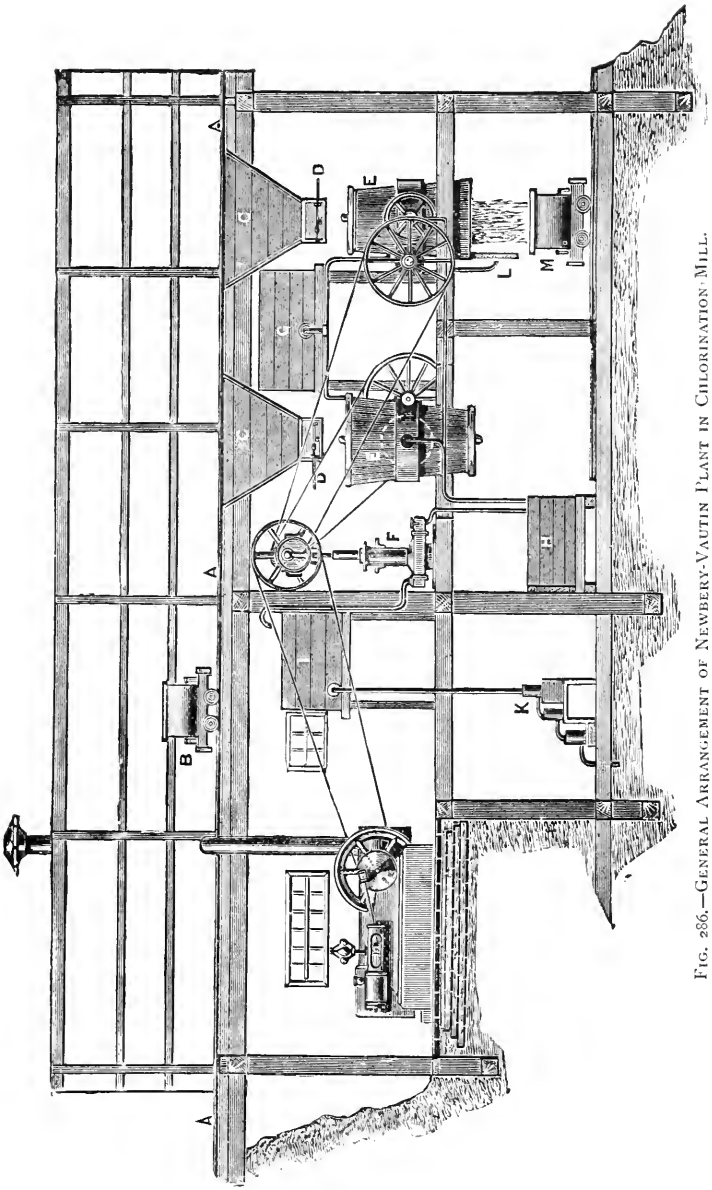


FIG. 286.—GENERAL ARRANGEMENT OF NEWBERY-VAUTIN PLANT IN CHLORINATION MILL.

Care must, of course, be taken to thoroughly wash out the soluble gold contained in the chlorinator, after which it is inverted, the lid (L) opened, and the contents discharged into the truck (M) and removed

to the waste heap. The process is thus rendered as automatic as possible, and with ordinary care the loss is reduced to a minimum.

Early in 1890, I had occasion to make a trial of this process upon a sample of refractory ore from Norway, with the following results which will be found interesting:—The ore weighed 4 tons 10 cwt., and consisted of quartz containing calcite and iron pyrites, assaying before treatment 10 oz. 8 dwt. of gold per ton of 2240 lb., partly in a free state and partly associated with iron pyrites. The ore was crushed, roasted, and chlorinated on the Newbery-Vautin system, and the total gold obtained was 5 oz. 18 dwt., or equal to 1 oz. 6 dwt. per ton of ore.

The Cyanide Process for Refractory Gold Ores.—The cyanide process differs from the chlorination in one very essential feature, and that is, that the auriferous ore does not require a preliminary roasting operation, except in the case of Tellurides as at Cripple Creek. The ore, whether as "tailings" or as pulp direct from the stamps, is conducted direct into large wooden vats, and is then treated with a weak solution of cyanide of potassium, which dissolves out the gold. This solution is then drawn off into a precipitating vat containing zinc turnings; the zinc is dissolved and the gold precipitated from the solution, to be collected and smelted into bullion.

Such is a brief outline of the process which has recently been brought into extensive and successful working, both in South Africa and America, for the recovery of gold from refractory ores. Properly speaking, no machinery is employed, unless the large wooden or steel vats come under that head. But so much has of late been heard of it in connection with the Witwatersrand mines, that a notice of it will not be altogether out of place in continuation of what has already been written on the roasting and chlorination of refractory gold ores.

On its first introduction it was thought necessary to agitate the material under treatment with the cyanide solution, in order to facilitate the extraction of the gold; but this idea has now been abandoned in favour of allowing the solution to percolate through the ore or tailings, which are charged into wooden or steel vats of a capacity of from 35 to 50 tons each. The vats may be either round or square. Those at the Robinson Gold Mines, Johannesberg, are circular, and have a capacity of 75 tons; while at the Langlaagte mines there are tanks to a capacity of 400 tons. The vats are filled to within a few inches of the top, and the surface of the ore levelled. A solution containing from ·5 to ·8 per cent. of cyanide is then introduced until the tank is filled, and is allowed to remain in contact with the ore for a period of about 12 hours.

The bottom of the vat is formed into a filter of coarse sand and pebbles, covered over with cocoa-nut matting, and is drained by means of an iron pipe leading to the precipitation vats. At the end of 12

hours a tap in this pipe is opened, and the solution is drawn off, being replaced by a fresh quantity in order to ensure the whole of the gold being dissolved. This second solution is allowed to stand for a period of from 6 to 12 hours, and is then drained off to the precipitation vat; after which the ore in the leaching vat is first washed with a weaker solution containing from ·2 to ·4 per cent. of cyanide, and finally with water. The weak solution is not allowed to drain into the same precipitation vat as the two former, but is run into a separate tank called the weak zinc box.

The cyanide of potassium is supplied in cases holding from 190 lb. to 195 lb. in the form of white cakes, and from these a concentrated standard solution is made, from which the dilute liquor can readily be prepared. The actual amount of cyanide used is about half a ton of the strong (·6 to ·8 per cent.) solution, and half a ton of the weak (·2 to ·4 per cent.) solution, for every ton of ore treated.

As the amount of cyanide solution required to dissolve the gold is extremely small, it is the practice in some works to pump it back into the same tank for about 36 hours before running it into the precipitation vat. By this means the consumption of cyanide is greatly reduced, and a much smaller quantity of it exposed to the action of the zinc.

The cyanide solution containing the gold is led for precipitation through an iron pipe to the "zinc box." At the Calumet Gold Mines in the States this box is made of wood, and is about 14 ft. long, divided into 14 compartments, each of which has a wire screen near the bottom upon which there is a 4-in. layer of zinc shavings. The boxes are so constructed that the solution is made to pass through the body of the shavings, which precipitates the gold and silver, if any, in the form of a blackish powder. A certain amount of zinc enters into solution to replace the gold; but this is not apparently deleterious to the process as the solution is pumped back after passing through the precipitation tanks for use again in the leaching vat, a certain amount of the standard cyanide solution being added in order to maintain its strength. The precipitated gold is collected and smelted in the usual manner.

The machinery used in connection with the cyanide process consists of stone-breakers, dry crushers, conveyers, elevators, roasting furnaces, and coolers, centrifugal pumps and steel vats and precipitating tanks, all of which are described elsewhere in this book. As the cyanide process is a complicated chemical one, I will refer my readers to special works written on the subject, such as Mr. Eissler's "Metallurgy of Gold," or "The Cyanide Process of Gold Extraction," by the same author.*

* London: Crosby Lockwood & Son.

CHAPTER XXV.

CONCENTRATION MILLS OR DRESSING FLOORS FOR THE ORES OF LEAD, ZINC, COPPER, ETC.

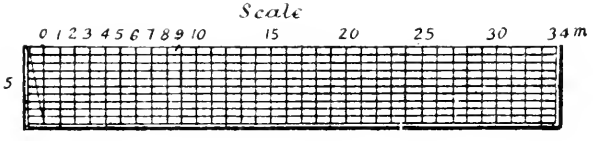
Mill at Arrayanes, near Linares, Spain, for Argentiferous Lead—Mill at Neuhof Mine, near Tarnowitz, Upper Silesia, for Galena and Calamine—The Cwmystwith Mill —Small Plant for Lead and Zinc Ores.

Lead Dressing or Concentration Mill on the German Model.—The German manufacturers of concentrating machinery justly attach great importance to the classification of the mineral, and divide their trommel systems with such care that the grains as sent to the jiggers are as near as possible all of the same size for each machine. This method will be noticed in the following description of a mill erected by the Humboldt Company, of Kalk, near Cologne, for the Arrayanes Mine, at Linares, in Spain. The mill is a large one, designed to and capable of treating 500 tons of ore in 10 hours. It is built on the slope of a hill, so that the ore runs automatically through the machines, thus avoiding much expensive handling and the elevation of the mineral for retreatment.

In the illustrations (figs. 287–293) the lettering is identical. They consist of a plan of the whole mill (fig. 287, Plate X.); a longitudinal section (fig. 288, Plate XI.) on the line A B of the plan; and various cross-sections (figs. 289–293, Plate XI.) through each of the departments.

The mineral arrives from the mine at *a* in the plan (Plate X.) and section (Plate XI.), and is tipped into the masonry kilns or bins, *b*, from whence it slides on to the fixed picking tables, *c*. These tables are covered with grates having holes 30 mm. square, and here the first classification commences.

The rich mineral is hand-picked out and sent to magazine. The mixed ore is trammed to the elevator, *f*, and on to the stone-breakers in department II.; while the ore which passes through the grates descends into department I., where it is classified in the two parallel sets of trommels, *d*. The holes in each of these sets in descending order are 22·6, 16, 8, 4 mm.



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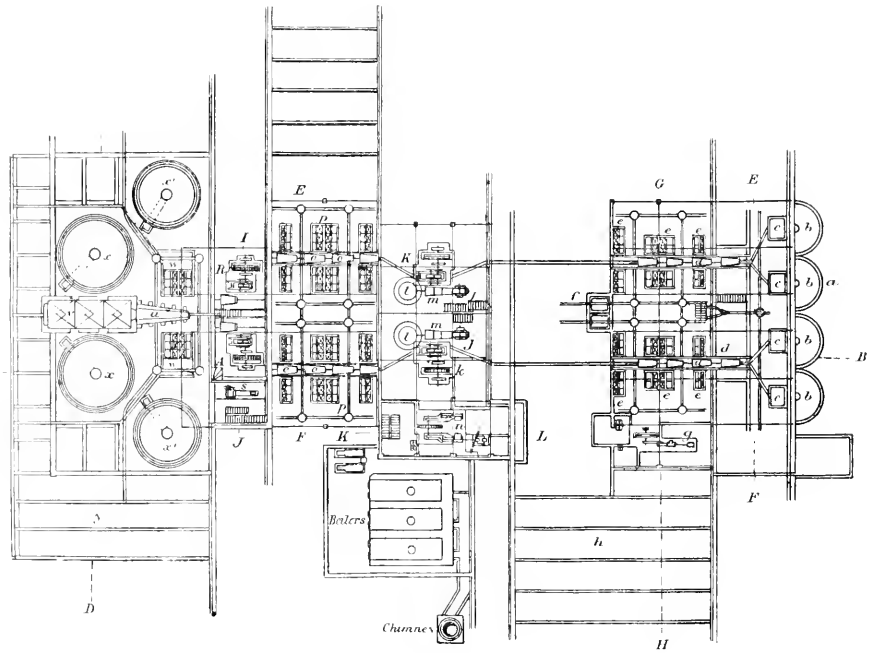

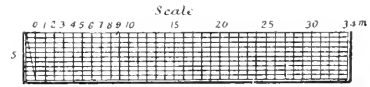

Fig. 287.—Plan of the Arrayanes Lead Concentrating Mill.

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There are two jiggers to each trommel, making in all the 16, shown at *e e*.

The waters used in the trommels and in the kilns is pumped back again by a centrifugal pump, *h*, in fig. 290, to the tank, *i*. This pump runs at 1500 revolutions per minute.

The water used in the jiggers of department I. is also pumped back by another centrifugal pump at, *h*, and used over again. This second pump runs at 600 revolutions. Department I. is driven by a separate engine, *g*, with a cylinder 300 mm. diameter × 400 mm. stroke, fitted with a separate condenser, and running at a speed of 105 per minute.

Passing on with the mixed ore—that is, the lumps of ore which require crushing in order to separate the rich from the sterile—we arrive at the two stone-breakers, *j j*, of department II.

These breakers have a jaw opening of 400 × 200 mm., and run at a speed of 200 revolutions. They are each followed by a double trommel, having holes of 16 and 18 mm., which take out the small stuff and send the coarse on to the revolving picking tables, *l l*, each of which is 3 metres diameter. A further separation of the rich from the poor by hand here takes place; the poor is swept off the tables, which are of the type shown in fig. 151, and passes direct into the roller crushers, *k k*, of which there are two pairs, one under each picking table.

The rolls have a diameter of 950 mm. (say 38 in.), and a face of 300 mm. (say 12 in.), revolving at a speed of 40 revolutions per minute. The crushed ore passes on to department III., where it is classified in two sets of four trommels, *o o*, shown in the plan (Plate X.), and in the sections (figs. 288 and 291).

These trommels have holes of 16, 8, 4, 2, 1 mm. respectively in each set, and there are two jiggers for each trommel, making in all the 16 shown at *p p*, in the plan and sections. The water is supplied by the California pump, *s*, and is pumped back to the tank, *t*, in fig. 288.

The departments II., III., and IV. are driven by a coupled condensing engine, *n*, on the plan, having cylinders each 350 mm. diameters (14 in.) × 700 mm. (28 in.) stroke, running at a speed of 100 revolutions per minute; the steam being supplied by three double-flued boilers, 8 metres long, as shown on the plan.

The mixed products from the jiggers which require enriching pass on to the two pairs of fine roller crushers, *r r*, in the plan and longitudinal section. These rolls are 700 mm. diameter × 280 mm. face (28 in. × 11½ in.), running at 45 revolutions. They are each followed by a guarantee trommel, *z z*, which prevents any ore coarser than 1·7 mm. from being carried on to the classifier, *u*. This classifier is one of

the type described on page 287 (fig. 192), with an ascensional current of water. It is $5\frac{1}{2}$ metres long, and supplies the four slime jiggers, *w w*.

The fine slimes are carried over the spitzkasten *v*, described on page 289, where they settle and thicken. The waste water flows over into the tanks, *y*, and the slimes are distributed over the Linkenbach tables, *x' x'*, of 6 metres diameter, and *x x*. of 7 metres (see page 315, and figs. 218, 219, 220).

The whole of the ore which arrived at the kilns has now been gradually classified and separated into marketable mineral and steriles, with as near an approach to an automatic action as is possible, and the results obtained are very satisfactory. The building is made of a framework of wrought iron girders, covered with corrugated iron.

The German firm who supplied the machinery always insist upon making an experimental trial of a few tons of the ore at their own works before they will recommend or supply any type of machinery, and this is a matter in which the English firms would do well to imitate them.

Mixed Ore Concentration Mill.—Subjoined is a description of a mill for the concentration of a mixed ore containing galena and calamine, built by the Humboldt Manufacturing Company, of Kalk, near Cologne.

The mine Neuhof, belonging to the Hugo Graf Henckel von Donnersmarck Company, at Carlshof, near Tarnowitz, in Upper Silesia, is situated at about two miles to the north of Beuthen, near the railway station of Scharley. At this mine some beds of galena, containing bunches of calamine in a dolomite gangue, are worked. The beds, which have a thickness of about 7 metres, are found at a depth of from 35 to 50 metres, and dip towards the south. At a greater depth of from 75 to 100 metres they lie upon layers of pyritiferous blende. The calamine and dolomite are often ferriferous. The galena is found in grains varying in size from 25 mm. (1 in.) down to fine sands and slimes, and is rarely found combined with the gangue cerusite (carbonite of lead); also occurs in a finely divided state, or as an incrustation upon the grains of galena. The mineral is comparatively soft, and the separation of the calamine from the galena presents no difficulty, because of the great difference in their specific gravities; but, on the other hand, the dolomite and calamine cannot be completely separated, for these two are intimately mixed up together, and form intermediate products of all kinds. The cerusite is somewhat porous, and it is probable that the lighter particles are floated off on the water employed in dressing.

The galena contains a certain amount of silver, and in the new dressing mill the points to be attained were a minimum loss of galena and cerusite, and the prevention of the loss of the lighter particles of cerusite.

The dolomite and calamine are intimately mixed together, and the former always contains more or less of the latter. The pure lumps of

FIG. 291.—SECTION E F.

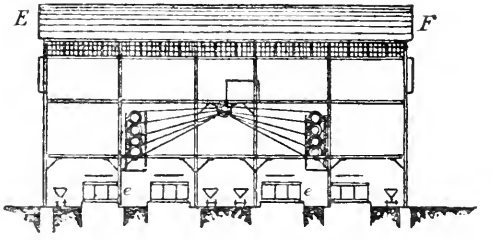


FIG. 292.—SECTION G H.

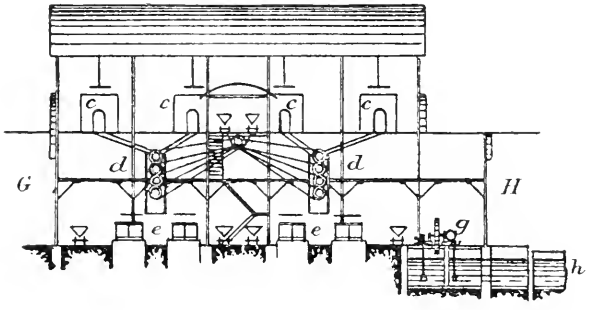
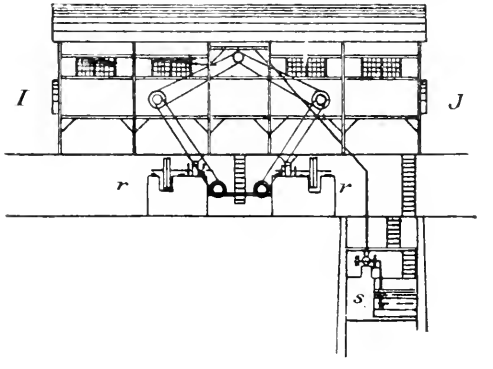


FIG. 293.—SECTION I J.



Mill.

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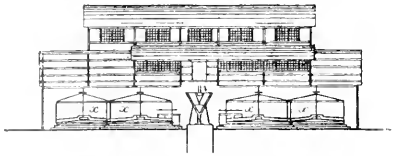

Fig. 289.—SECTION ON LINE, C D.

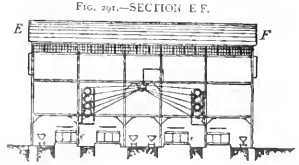

Fig. 291.—SECTION E F.

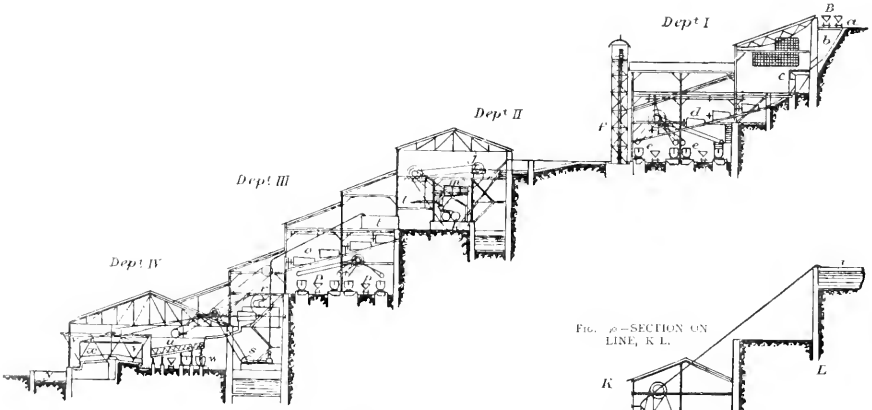

Fig. 288.—SECTION ON LINE, A B.

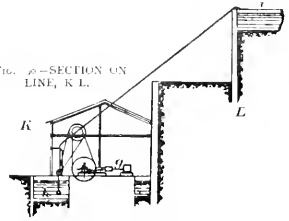

Fig. 290.—SECTION ON LINE, K L.

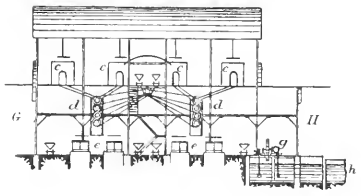

Fig. 292.—SECTION G H.

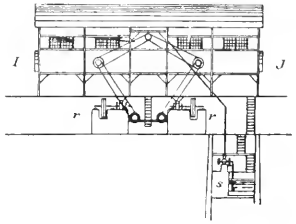

Fig. 293.—SECTION I J.

Figs. 288 to 293.—Sections of the Arrayanes Lead Concentrating Mill.

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calamine contain about 25 per cent. Zn., but ore containing over 8 per cent. Zn. is mixed in the smelting furnaces with richer mineral. In the former dressing mills the large lumps of mixed mineral were broken either by hand or in a rock-breaker, and afterwards separated by hand-picking, and when the minerals were intimately mixed their separation could not be effected at a profit.

The calamine formations in Upper Silesia are often very argillaceous, and in the mine under notice the clays were so tenacious that in the washing trommels they formed balls which contained precious mineral, and this could not be divided even when abundance of water was used. In designing the new dressing mills it was absolutely necessary to prevent the formation of these balls of clay, as they always contained the richest mineral, and after numerous experiments it was found that this could be attained by using the Criekboom trommels.

The preliminary trials made with a quantity of the mineral sent for experiment to the works of the Humboldt Company, at Kalk, near Cologne, gave the following results, which furnished the basis for the designing of the works afterwards erected.

After leaving the Criekboom trommel the slimes were passed on to a trommel having holes of 2 mm., and were then classified by means of a classifier, with an upward current of water and two spitzkasten.

The classified slimes were fed respectively into a 3-compartment jigger, a percussion or Rittinger table, and a rotating table of 4 metres diameter. The products were galena, calamine, and steriles.

The material larger than 2 mm. was classified in trommels as follow: 2 to 2·8 mm., 2·8 to 4 mm., 4 to 5·6 mm., 5·6 to 8 mm., 8 to 11 mm., 11 to 16 mm., and 16 to 22 mm., each category being sent to a jigger, and the stuff larger than 22 mm. being hand-picked.

The *quantitative results* of this trial were as follows, the total weight of ore treated being 8970 kg.:

Galena: Grains from 2 to 22 mm.	894 kg.
,, less than 2 mm.	129 ,,
Slimes from Rittinger	12 ,,
,, Rotating table	5 ,,
	1040 kg.

Weight production of Galena		= 11·60 %.
,, ,, Calamine I.	3384 kg.	= 37·20 %.
,, ,, ,, II.	1258 ,,	= 14·00 %.
,, mixed products	38 ,,	= 0·42 %.
,, sterile	3290 ,,	= 36·78 %.
	8970 kg.	100·00 %.

The qualitative results by analysis were as follows:

(*a*) GALENA.

		Grammes.
Hand picked larger than 22 mm.	82·41 % Pb.	with 14·74 Ag. per 100 kilos.
Grains from 2 to 22 mm.	76 to 82·55 % Pb.	,, 25 to 101·52 ,, ,,
,, less than 22 mm.	72·32 % Pb.	,, 81·2 ,, ,,
Slimes from Rittinger and rotating tables	62·58 to 70·13 Pb.	,, 24 to 50 ,, ,,

The average assay of the crude ore was 7·75 per cent. Pb., 8·03 per cent. Zn., and 8 to 10 per cent. of iron, per ton of 1000 kilos.

(*b*) CALAMINE.

Hand-picked larger than 22 mm. gave	16 % Zn.
Grains from 2 to 22 mm. ,,	11·43 to 21·53 % Zn.
Sands under 2 mm. ,,	16·37 % Zn.
Slimes from the Rittinger table ,,	14·37 % Zn.
,, ,, Rotating table ,,	8 % Zn.

The calamine No. II. was enriched up to 12·65 per cent. The steriles contained an average of 5·40 per cent. Zn. The calamine was of an average percentage of 14·76.

The calamine in large pieces, which was not subject to this experiment, contained an average of 17 to 18 per cent. Zn., while the sterile slimes from the trial held 1 per cent. Pb., and the mixed products 25 to 47 per cent. Pb. with 18 grms. Ag per 100 kg. of mineral.

The result of the trial was to prove the efficacy of the Criekboom trommel, and the utility of the tables in saving the silver, which would otherwise have been lost in the slimes. In order, however, to ease the work of the tables, it was proposed to employ the Bilharz circular jiggers and the fixed Linkenbach table, whose diameter could be as large as 10 metres, and which would thus give the slimes a longer interval of time in which to classify themselves before leaving the table.

The results of the experiment being thus favourable, it was decided to erect a new concentration or dressing plant, capable of treating 250 tons per 20 hours; in actual practice, however, the plant was found able to dress 300 tons in the same time.

The Humboldt Company was entrusted with the manufacture and erection of the dressing machinery, and the boilers used were of the well-known "Root" system. The erection of the buildings was commenced in August, 1884, and the first trial run was made on May 2nd, 1885; the mill was in full working order by the second half of the same month.

The cost of the complete installation, including the piping, but excluding the belting, was £5500, and the two boilers, each with a heating surface of 128 square metres, cost £500 apiece. The following is a description of the works which were designed for the enriching of a

Fig. 294.—PLAN

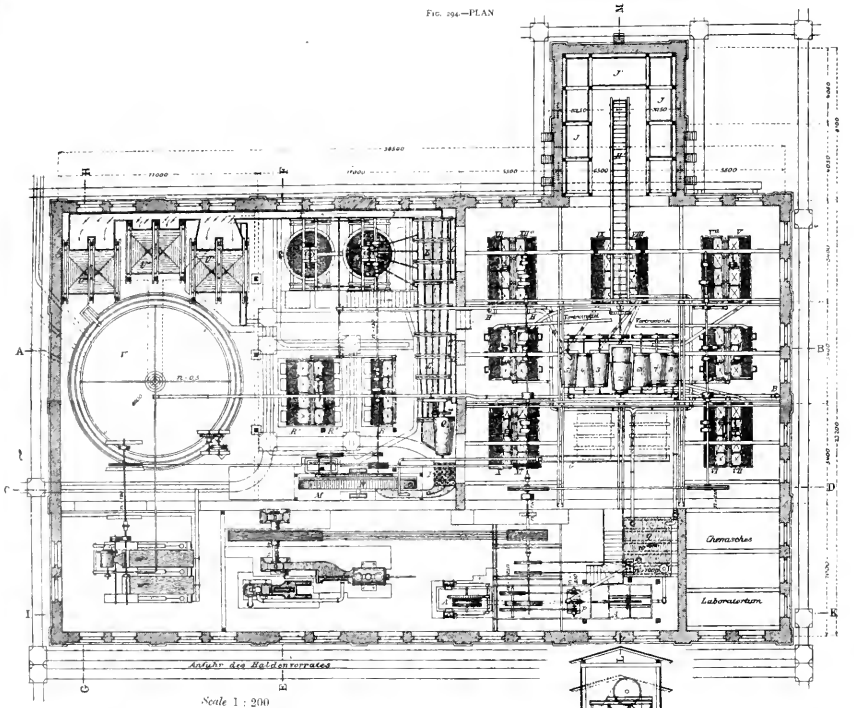


Fig. 295.—PLAN OF TOP FLOOR

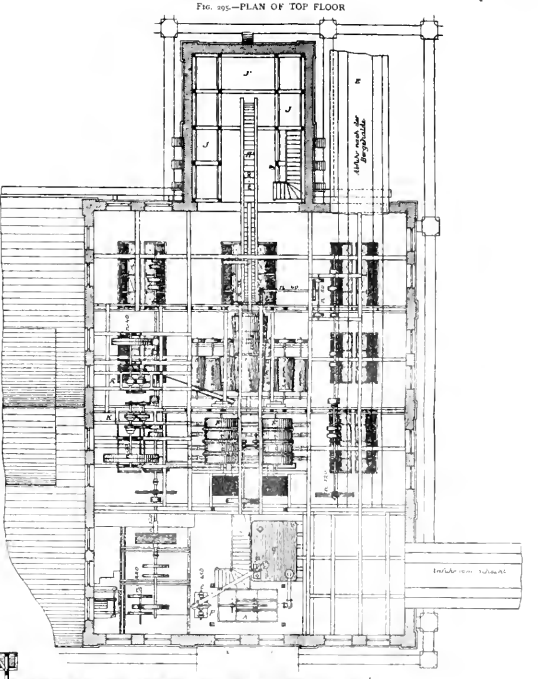


Fig. 296.—SECTION ON LINE I K

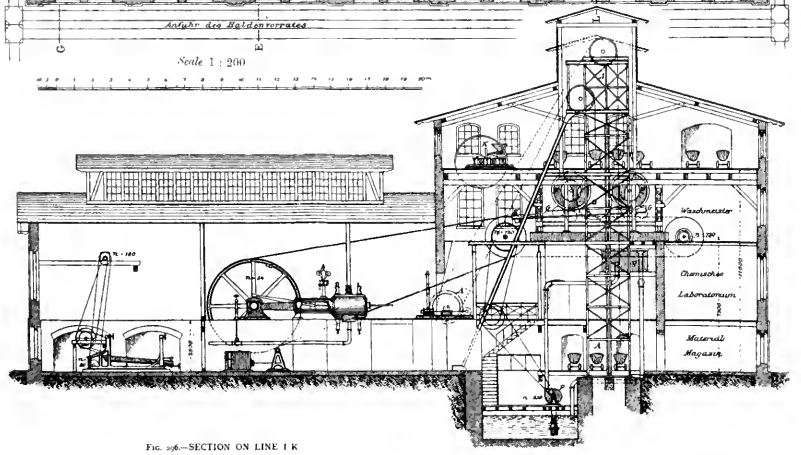
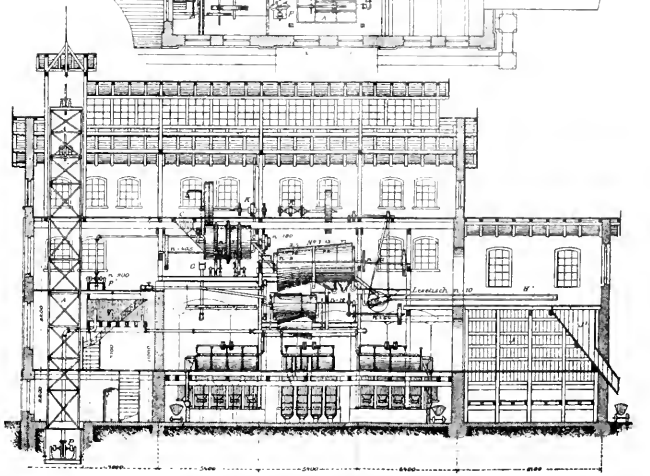


Fig. 297.—SECTION ON LINE L M.



Figs. 294 to 297.—The Neuhof Concentration Mill for Lead and Zinc Ores.

[To face page 448.

mineral containing argentiferous galena, cerusite, and calamine, with a gangue of dolomite. The mineral arrives in trucks, and passing through the doors (A A), of fig. 294, Plate XII., is run into a cage, and raised to the upper floor of the works at a height of 11 metres above the ground by means of a small winding engine.

The waggons hold 450 to 500 kilos. (say half a ton) of ore, and are side tipping.

On the top floor there are two gratings (C C) of an area of 1 metre × 1·40 metre, the bars being 70 mm. apart. The waggons are tipped on to these, and the mineral is helped to pass through by means of a supply of water. The lumps which are too big are put on one side, and as their proportion is very small they are separated by hand. The mineral is subject to a preliminary sorting in the mine, so that all mineral ready for hand-picking can go direct to that department.

The mineral which passes through the gratings (C C) passes on to the two trommels (F F) in which a current of water forms with the ore a liquid mud, which is constantly stirred up in the trommel. The covering of the trommel is in sheet steel, and in the inside some steel blades are fixed in such a manner as to force the mineral forward, while at the same time a series of iron knives, revolving in the interior of the trommel at a speed of from 200 to 300 revolutions per minute, break up the balls of clay, and thoroughly mix up the mass.

Each of the trommels (F F) has a diameter of 1600 mm. and a length of 2·500 metres, and runs upon friction wheels.

At the mouth of the trommel there is a sieve with longitudinal slots of 4 mm., so that the clayey mixture and all the grains less than 4 mm. pass through this sieve into the general sluice (G) which leads them to a classifier, with upward current of water (H), in which they are separated into two categories.

1st. The large grains which have traversed the upward current of water, and are directed with a part of the water to the trommel No. 2.

2nd. The fine sands and slimes which are thrown over by the water, and which are led direct to the slime department.

The mineral matter coming from the washing trommel (F) which is over 4 mm. in size, passes on to the large trommel No. 1, where a preparatory classification is effected. This trommel is 4·50 metres long, with an average diameter of 1·65 metre. It has two coverings; the exterior has holes of 2·5, 13, and 17 mm., the interior has holes of 10 and 22 mm.

The products from this trommel are divided as follows: 17 to 22 mm. to the jigger No. I.; 13 to 17 mm. to No. II.; 10 to 13 mm. to the jigger No. III.

The two finer sizes each pass on to the two series of trommels placed underneath Nos. 3 and 6.

The lumps larger than 22 mm. are swept by a current of clean water on to an endless belt (H'), figs. 294, 295, and 296, where they are hand-picked by a number of women.

The picked lumps are thrown into openings on each side of the belt, and through them into the magazine (J'). The steriles fall off the end of the belt into the magazine (J'). The mineral is fed automatically from the magazines into waggons as and when required.

The trommel No. 2, referred to above, is under the large trommel No. 1. It receives the mineral which has passed through the upward current of water in the damper (H) and divides it amongst the trommels No. 3 to No. 8. All these trommels are conical, 1·650 metre long × 900 mm. average diameter. The trommel No. 2 is double; the interior covering is perforated with holes 1·9, and 2·5 mm. diameter, the exterior with hole of 1·3 mm. The six other trommels are simple, with holes respectively of 8—5, 4—4, 1·9, 1·3, and 1 mm. diameter.

The trommel No. 2 gives a product 1·3 to 2 mm., which is sent to the jigger No. IX. The product 1·9 to 2·5 mm., goes to the jigger No. VIII. The mineral under 1·3 mm., goes to the trommel No. 8, and that larger than 2·5 mm., to the trommel No. 5.

The mineral rejected from trommel No. 3 goes to the jigger No. IV.								
,,	,,	,,	,,	,,	4	,,	,,	V.
,,	,,	,,	,,	,,	5 respectively to Nos. VI. and VII.			
,,	,,	,,	,,	,,	6	,,	,,	VIII.
,,	,,	,,	,,	,,	7	,,	,,	IX.
,,	,,	,,	,,	,,	8	,,	,,	XI.

And lastly, the mineral passing through the holes of the trommel No. 8 is treated in the jiggers XII. *a* and *b*.

The channels are all of such a slope as to admit of the mineral passing automatically from one machine to another. The trommels are all kept clear by means of water-sprays, and the perforated sheetings are fixed by means of bolts and angle iron, so that they may be readily repaired.

The preparatory trommel No. 1 is driven from the main shafting, but by means of intermediate gearing, so as to reduce the speed. The following seven trommels are driven by one belt only, which, starting from the axle of No. 1, winds over and under all the pulleys or the trommels 2 to 8.

The jiggers I. II., III., and IV. are of three compartments, with side delivery, and throw off the finished products through regulating sluices.

The other jiggers are of four compartments, with sieves 450 mm. broad × 750 mm. long. The body of the jiggers is made of pitch-pine planks 60 mm. thick, grooved and tongued. The sieves have square

holes, and are fixed in their places by means of copper wire upon a grating with fine bars. The water and mineral can flow out from the bottom by means of a valve, closed and opened by means of a lever.

The jiggers are all upon the differential lever-stroke principle shown in fig. 202, page 297; the descent of the piston is rapid and its ascent slow, and thus effects a better classification than the usual eccentrics, for in the former case there is not the suction which is always present in the latter; and lastly, the friction and wear and tear are less. The levers are so arranged that whilst one half of the pistons is descending the other half is rising, and this disposition, in conjunction with the circular masses forming flywheels, permits of a much more even running of the jigger and less strain on the belt.

The product of the jigger is—upon the first sieve, pure galena; from the second a mixed product, dolomite or calamine mixed with gelena; on the third a rich calamine (No. 1); on the fourth, a poor calamine (No. 2), and the steriles which pass through the adjustable opening leading from the fourth compartment. The mineral matters thus separated are automatically transported to the magazines, the bottoms of which are made of perforated sheeting so as to allow of drainage; and this sheeting is removable, and permits the mineral to fall automatically into the trucks.

The steriles are thrown away; the mixed products are relifted to the upper story, and ground in the rollers (K K), from which they pass to their respective trommels.

Such is the arrangement for washing, hand-picking, classifying, and jigging the coarser grains; and we now pass on to the *slime* department, which is situated to the west of the other buildings, and is fed by—

1. The overflow of the classifier with upward current (H).
2. „ „ „ „ placed in front of the jiggers XII. and XII.*a*.
3. The slimes which are deposited in the coarse jiggers.
4. The mud deposited in the settling tanks of the mill.

The slimes from the jiggers run into a tank (M), from which they are lifted by means of an elevating wheel (N), of fig. 294, Plate XII., and fig. 300, of Plate XIII. This wheel has a diameter of 6·50 metres, and empties the slime water into the trough (O) into which the overflow of the classifier (H) is also emptied.

The overflow from the apparatus (H′) is emptied direct into the classifier (L), figs. 298, 299, and 301. The mud coming from the slime pits is deposited in the basin (M) to be elevated by the wheel (N). In order that any coarse grains may not find their way into the classifier (L) the slime waters are first of all made to pass through a guarantee trommel having holes of $1\frac{3}{4}$ mm. The grains rejected by this trommel return to the jiggers, but the slime waters which pass through it are led to the classification (L).

If all the water raised by the elevating wheel were allowed to flow through the guarantee trommel, the strong current of water would certainly carry grains of sand, the fine sieving would be impossible. In order to avoid this inconvenience a concentration apparatus (P) is fixed near the entry to the trommel. Here the waters from the elevating wheel are divided into two parts—1st, the coarse sands which go on to the guarantee trommel; 2nd, the overflow which passes direct to the classifier (L).

This piece of apparatus is made of wood of a length of 10·50 metres, of which a description will be found on page 287, and in figs. 192 to 195. Throughout its length there is an inner lining converging to a point at the bottom—shown in section at L, fig. 266—but leaving a longitudinal slit at the bottom, through which a constant upward current of water ascends; and this, in conjunction with the stream of slimes, whose speed is greater at the entry to than at the exit from the classifier, acting upon the tendency of the mineral matter to fall according to its gravity and size, classifies the grains which pass on to the slime jiggers through syphon tubes, as follows:—

1st. To the three jiggers R′ R″ R‴ each of four compartments similar in all respects to those before mentioned. Here the product obtained are galena, a mixed product, calamine No. 1, calamine No. 2, and steriles.

2nd. To the first circular or Bilharz jigger (s′) which yields a product containing 25 to 30 per cent. Pb, and throws off the rest to a second jiggers (s″) placed on a lower level. This jigger produces a rich calamine, and discharges into the main waste water channel. It is described fully on page .

The overflow of the classifier (L) is divided between the three spitzkasten (v′ v″ v‴) in which the fine slimes are concentrated. These latter are conducted by means of a syphon tube passing under the floor to the centre of the Linkenbach table, V., for a full description of the action of which see page 313, and figs. 218 to 220.

The products of the table are accumulated in four cases, of which one is under the spitzkasten (v′) and the three others are outside the building.

The waste waters from the spitzkasten and the cases of the table pass first of all into four preparatory basins, and then into the main slime pits, where they are clarified by settling. Of these there are four, each of an area of 40 metres and a depth of 4 metres. A single basin is sufficient for the accumulation of slimes during two-and-a-half to three months. They are constructed in masonry, and in the centre of the four walls is a circular pit, at the bottom of which are the mouths of four galleries, each of which ends at the lowest point of each of the basins, which is closed with planks.

When it is desired to empty a basin the planks are removed, the slime loaded in trucks, which are run to the pit and raised by a winch.

The clarified waters are led back to the centrifugal pump (P), by means

Fig. 298.—SECTION ON LINE A B.

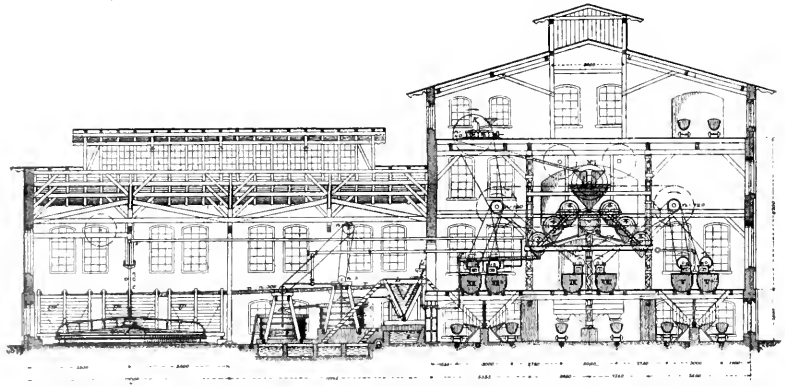
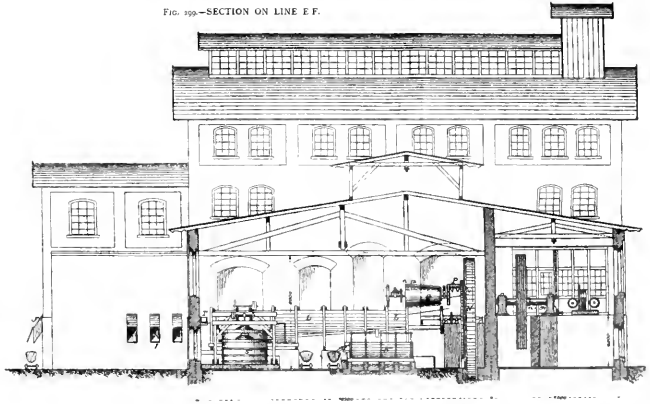


Fig. 299.—SECTION ON LINE E F.



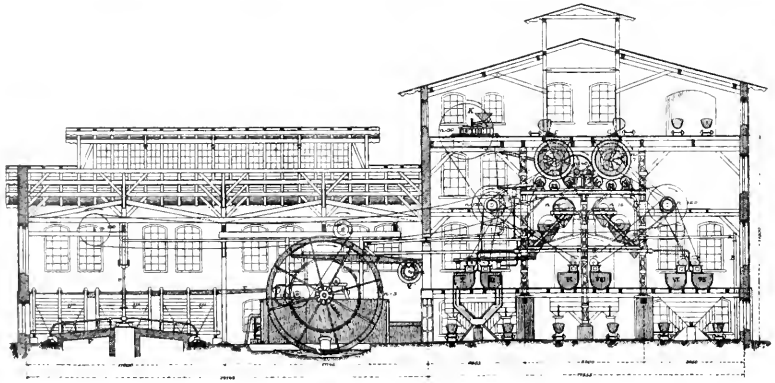


Fig. 300.—SECTION ON LINE C D

Scale 1 : 200.

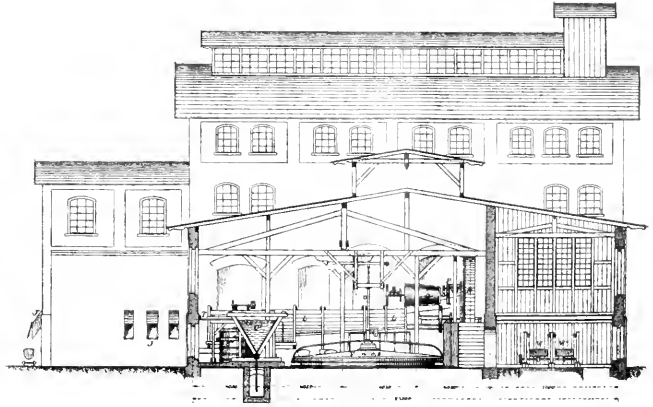


Fig. 301.—SECTION ON LINE G H

Figs. 298 to 301.—The Neuhof Concentration Mill for Lead and Zinc Ores.

[*To face page* 452.

of which they are lifted to a reservoir 9 metres higher, from which point again a part of the water is raised another 9 metres by means of the centrifugal (P′). (See figs. 296 and 297, Plate XII.)

The classifying trommels, the classifiers, picking table, and Linkenbach table are supplied with fresh, clean water, which is supplied from a reservoir at some distance from the mill. All the other machines receive the clarified water from the settling pits.

In the driving gear the use of toothed gearing has been minimised, and in no case are cone wheels used. There are four main lines of shafting, of which the principal is driven by means of cables from the steam-engine. To these the machines are connected by means of india-rubber belting. All the shafts are turned for their full lengths, and the pulleys are all made in halves—split pulleys.

The engine has a cylinder 620 mm. diameter stroke, 1250 metres steam-jacketed fitted with Zimmerman valve, and running at a speed of 54 per minute. The speed of each separate apparatus is marked on the plans thus: *n* 120, *n* 150, and so on. The condensed water from the engine is turned into the settling pits, and so to the centrifugal pump. It is hoped that this will prevent the mill from being frozen up in the winter.

The galena and calamine are trammed to the smelting furnaces for lead and zinc respectively.

In the month of August, 1885, the total amount treated in the mill was 6750 tons, of which 5160 came from old waste heaps, and 1640 from the mine directed.

The results of the milling of this amount were:

Galena	15	tons hand-picked.
,,	76·65	,, coarse jiggers.
,,	88·8	,, fine ,,
,,	34·5	,, coarse slimes.
,,	5·05	,, fine from tables.

Total 220 tons = 3·26 per cent. of the crude ore.

Calamine	196	tons hand-picked ore.
,,	228	,, coarse jiggers.
,,	177·5	,, fine ,,
,,	80·0	,, slimes from tables.

Total 681·0 tons = 10·10 per cent. of crude ore.

In September 5561 tons of crude ore gave

Galena	230 tons	= 4·14 %.
Calamine	600 ,,	= 10·7 %.

The galena from the jiggers, I. to VIII., assayed:

78 to 84 per cent. Pb. The Calamine I., from 15 to 34 per cent. Zn., and the Calamine II., from 10 to 20 per cent. Zn.

The steriles assayed on an average 0·3 per cent. to 0·5 per cent. Pb., and from 4 to 5 per cent. Zn.

The jiggers, IX. to XII., gave:

Galena	from 60 to 75 % Pb.
Calamine I.	,, 18 ,, 30 % Zn.
,, II.	,, 10 ,, 15 % Zn.

The steriles as above.

The fine slime jiggers gave:

Galena	70 to 76 % Pb.
Calamine I.	15 ,, 23 % Zn.
,, II.	9 ,, 13 % Zn.

Steriles with 0·5 per cent. Pb. and 5 to 6 per cent. Zn.

The circular jiggers, Bilharz, enriched the slimes on the first sieve to 20 to 26 per cent. Pb., and the second sieve gave a product containing 10 to 12 per cent. Zn., with 2 to 3·5 per cent. Pb.

The steriles gave 0·75 per cent. Pb. and 6 to 8 per cent. Zn. The calaminiferous slimes were enriched on the Rittinger tables (percussion) W and W″ (fig. 294, Plate XII., and fig. 301, Plate XIII.).

The product from the Linkenbach table were lead slimes with from 50 to 60 per cent. Pb., and calamine slimes with 8 to 10 per cent. Zn., and 1½ to 2 per cent. Pb.

The slimes from the Linkenbach table contained ½ to 1 per cent. Pb., and 6 to 9 per cent. Zn.

The slimes enriched on the percussion tables yielded from 40 to 46 per cent. Pb.

The quantity of silver contained in the dressed products was as follows:

Jiggers I. to III. .	42 to 62 grammes of Ag per 100 kilos. of mineral.
,, IV. ,, X. .	60 ,, 120 ,, ,, ,, ,, ,,
,, XI. ,, XII. .	80 ,, 100 ,, ,, ,, ,, ,,
The three fine jigs .	80 ,, 100 ,, ,, ,, ,, ,,

The concentrated slimes from the Bilharz jiggers, the Linkenbach table, and the percussion table gave 50 to 60 grammes of silver per 100 kilos. of mineral.

The hand-picked mineral contained 24 grammes Ag.

The *cost* of the whole milling operations amounted to 0·125 francs per 100 kilos. of mineral, which is equal to about 1*s.* per ton of crude ore, a price which will compare very favourably with that of any other

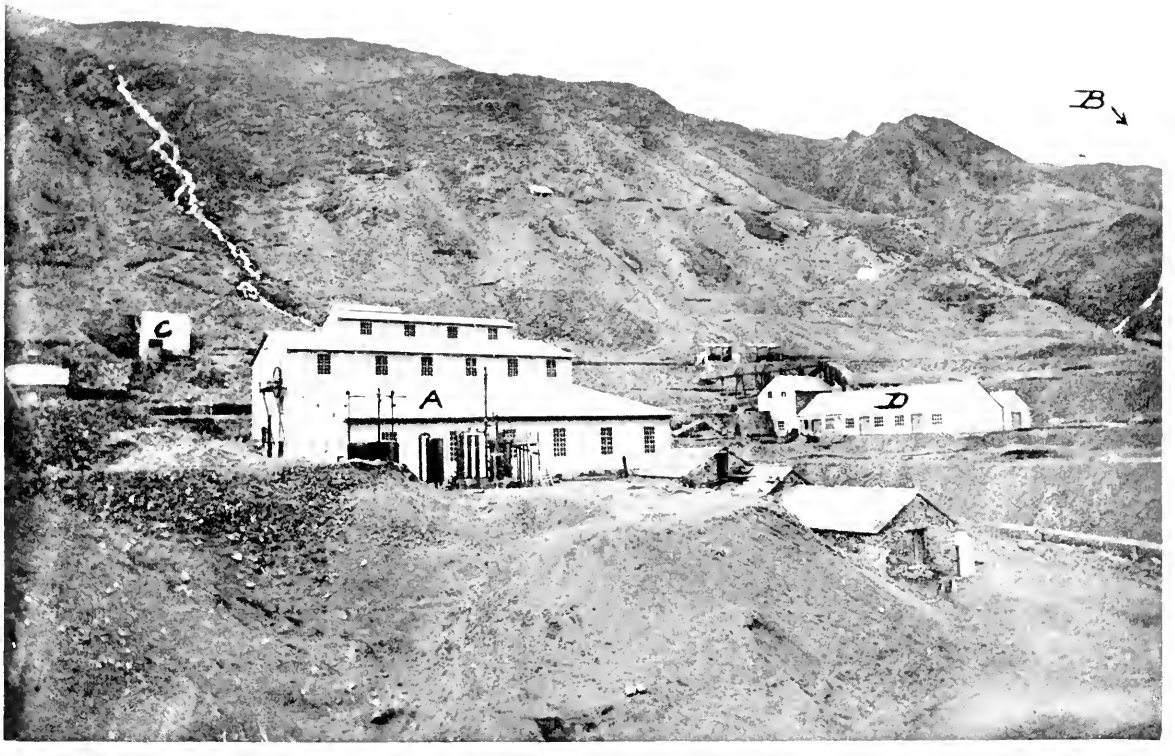


Fig. 302.—The Cwmystwith Lead and Zinc Ore Concentrating Mill.

To face page 434.

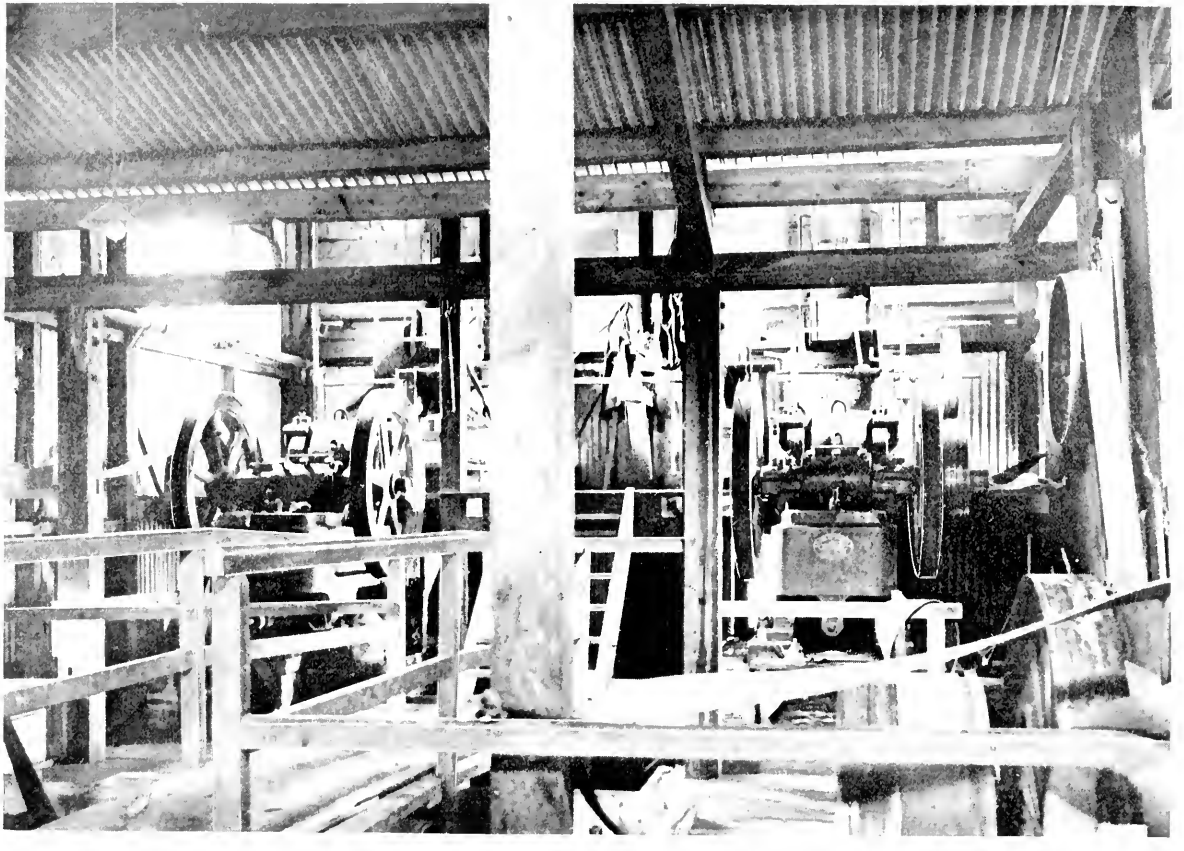


Fig. 303.—View of Interior of the Cwmystwith Concentrating Mill.

To face page 454 after PLATE XIV.

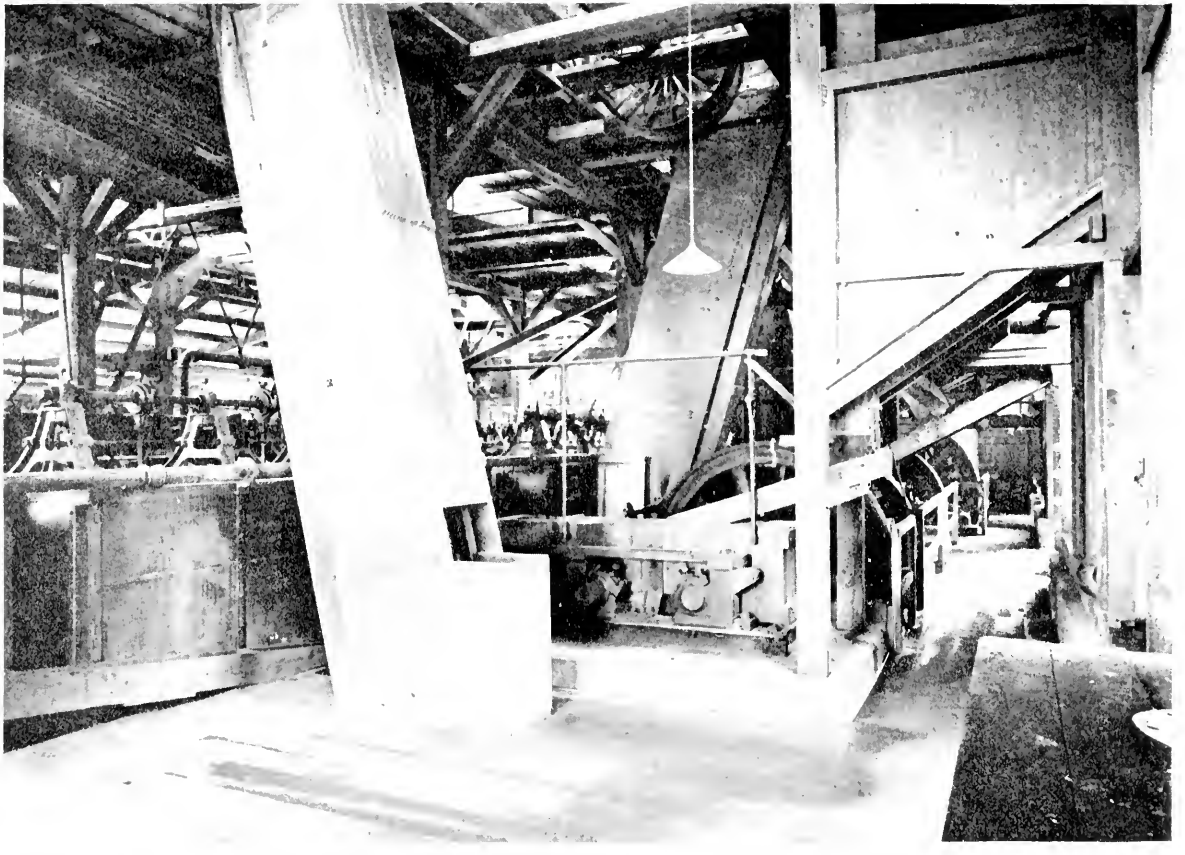


Fig. 304.—The Crushing Rolls and Elevators at the Cwmystwith Concentrating Mill.

To face page 454, after Plate XV.

system of dressing, while the results obtained were very good, considering the complicated nature of the ore which was under treatment.

The plans of the mill will well repay a careful study; and it will be noticed that the whole operation is automatic, the mineral not being touched by hand until it is finished with, while the products fall direct from the jiggers into the tram-waggons placed below.

Cwmystwith Concentrating Mill.—The 100-ton lead and blende concentration plant erected at the Cwmystwith Mine, in Cardiganshire, is one of the most recent installations of this kind, and was built from designs prepared by Mr. J. Buss, Ph.D., and myself. The machinery was supplied by the Lührig Ore Concentration Company, Limited, of 32, Victoria Street, London, S.W., and was erected under my own supervision, as consulting engineer to the mining company.

The general outside arrangement is shown in fig. 302 (Plate XIV.), taken from a photograph; and various views of the interior, of a similar kind, are given in Plates XV.—XIX. The main building (A) contains the concentrating machinery, which is shown in plan and section in Plate XX. The motive power is supplied by a 120-horse-power, Vortex turbine made by Messrs. Gilbert Gilkes & Company, of Kendal, working under a head of 190 ft. The stream of water shown at B is the overflow at the upper end of the turbine pipes, and the lower end of the 3-mile water-course running up the valley until it joins the river Ystwith which is the source of water supply. In addition to this a small water gas-plant is seen in front of the mill which furnishes gas to the engines inside as auxiliary power when water is scarce.

In the building marked C the air compressing plant described on page 174 is fixed, and this is driven by a Pelton wheel of 168 horse-power, working under a head of 800 ft. The water for this Pelton is obtained from a series of lakes on the hill above, the overflow from which is seen streaming down the hill. The arrangement of the gearing for the Pelton wheel will be found described on pages 18-19. The waste water from this wheel supplies the mill with water for the concentrating machinery sufficient for 10 tons per hour of crude ore.

The buildings marked D are the smiths', carpenters' and fitters' shops and saw mill; while in the upper portion is placed the small 15 horse-power Pelton and dynamo used for the electric lighting of the mill. This is described on page 19. The water for this Pelton is derived by a branch-pipe from the main Pelton pipe-line; and the wheel in addition to driving the dynamo is used as the motive power for the saw mill, replacing a 30-ft. waterwheel originally placed there for that purpose. The mineral is trammed from the mine, and after being weighed is tipped into the hoppers in the rear of the mill, as shown on Plate XX. The concentrates of lead and blende are trammed from the mill to the ore

bins, seen in front of and below it, and here after being drained, mixed and sampled they are bagged for sale.

The gangue is quartz and slaty rock and so presents no difficulty in its separation from the mineral.

The prevailing feature in the design of the plant is the gradual reduction of the ore, so as to avoid as far as possible the crushing of the ore further than the point required to liberate the grains of mineral from the gangue—in fact to smash the shell of the nut without damaging the kernel. The crushing is followed by the close sizing of the ore, after which it passes on automatically to the various concentrating machines.

The system of gradual reduction also avoids the creation of an undue amount of slime, and thus diminishes the loss of metal from this cause, which loss alone has in many instances been the reason of failure in other systems. Nor is this the only benefit, for the capacity of the mill is materially increased by the avoidance of useless crushing of the ores, and the working expenses decreased. Another great point is the automatic nature of the whole arrangement, for, as will be seen from the following description, the ore after entering the mill is practically untouched by hand until it leaves it in the form of concentrates or tailings. This, while also reducing the working expenses, makes the plant to a large extent independent of unreliable and unskilled labour.

The general idea is that the plant consists of two distinctly separate systems, in one of which the crude ore as it comes from the mine is treated; while in the other the middlings or "chats" resulting from the first system, are retreated. The keeping apart of the two classes of ore is a distinct advantage as not only are the middlings richer in metal than the crude ore, but they are also in a finer state and will, when recrushed, produce a greater proportion of fine sands which will require finer jigging than those from the first section.

Referring now to the plan and section of the Cwmystwith Mill as shown in Plate XX. (p. 458), the ore from the mine is trammed into the storage hoppers, which have a capacity sufficient for one day's run. These hoppers are fitted with sliding doors as shown in fig. 303, which regulate the feed of the ore on to the shaking screens (1) of Plate XX. These screens have perforated bottoms with 1-in. holes, and receive a longitudinal kick which causes the large ore to travel towards the stone-breakers (2), while the small stuff falls through the screen, and so into the main sorting trommel (3), where the large pieces, now broken to road metal size, also join them. This trommel is provided with a double mantle, the inner screen having holes of $1\frac{1}{4}$-in. and the outer screen $\frac{1}{2}$-in. The fine stuff that falls through the $\frac{1}{2}$-in holes goes straight to the main elevator (4), and is raised to the sizing trommels.

The sizes between $1\frac{1}{4}$-in and $\frac{1}{2}$-in. fall on to the two crushing rolls (5 and 6), while the sizes above $1\frac{1}{4}$-in. are discharged on to a picking

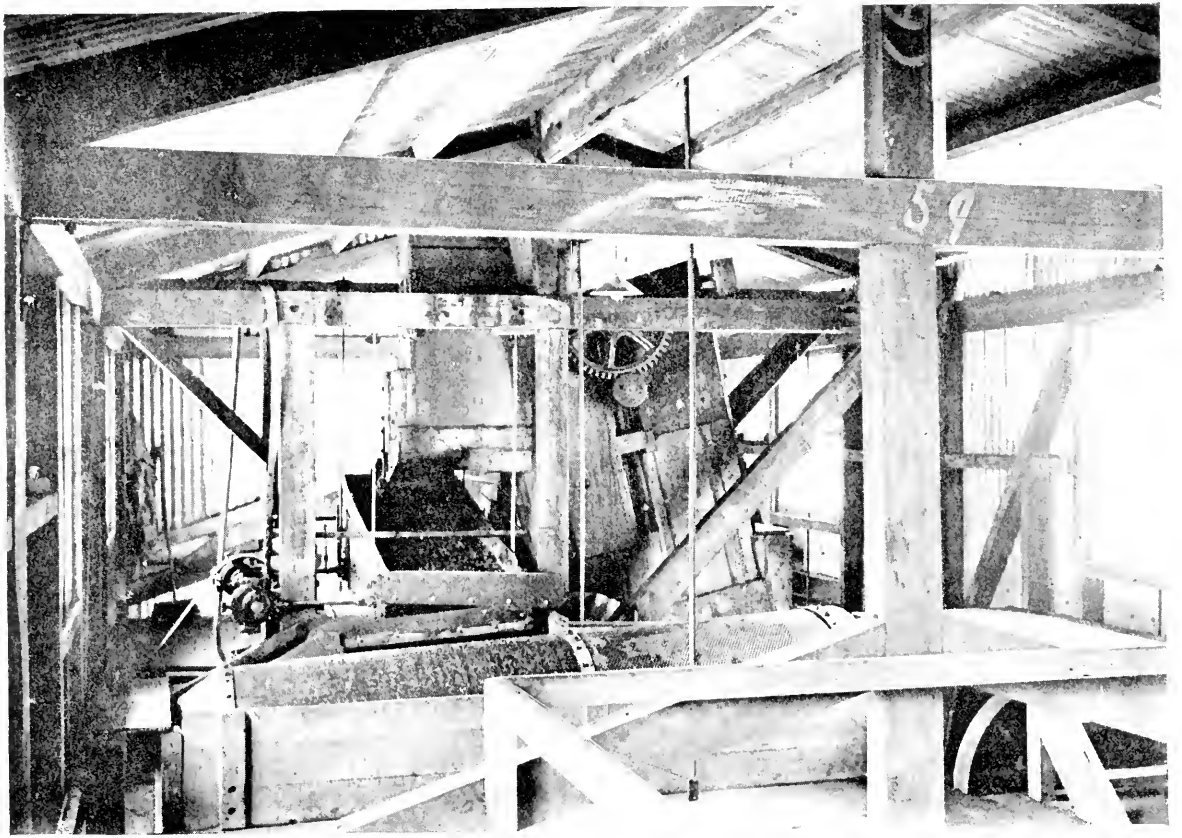


Fig. 305.—Vibro-screen Top of Elevator and Trommel at Cwmystwith Concentrating Mill.

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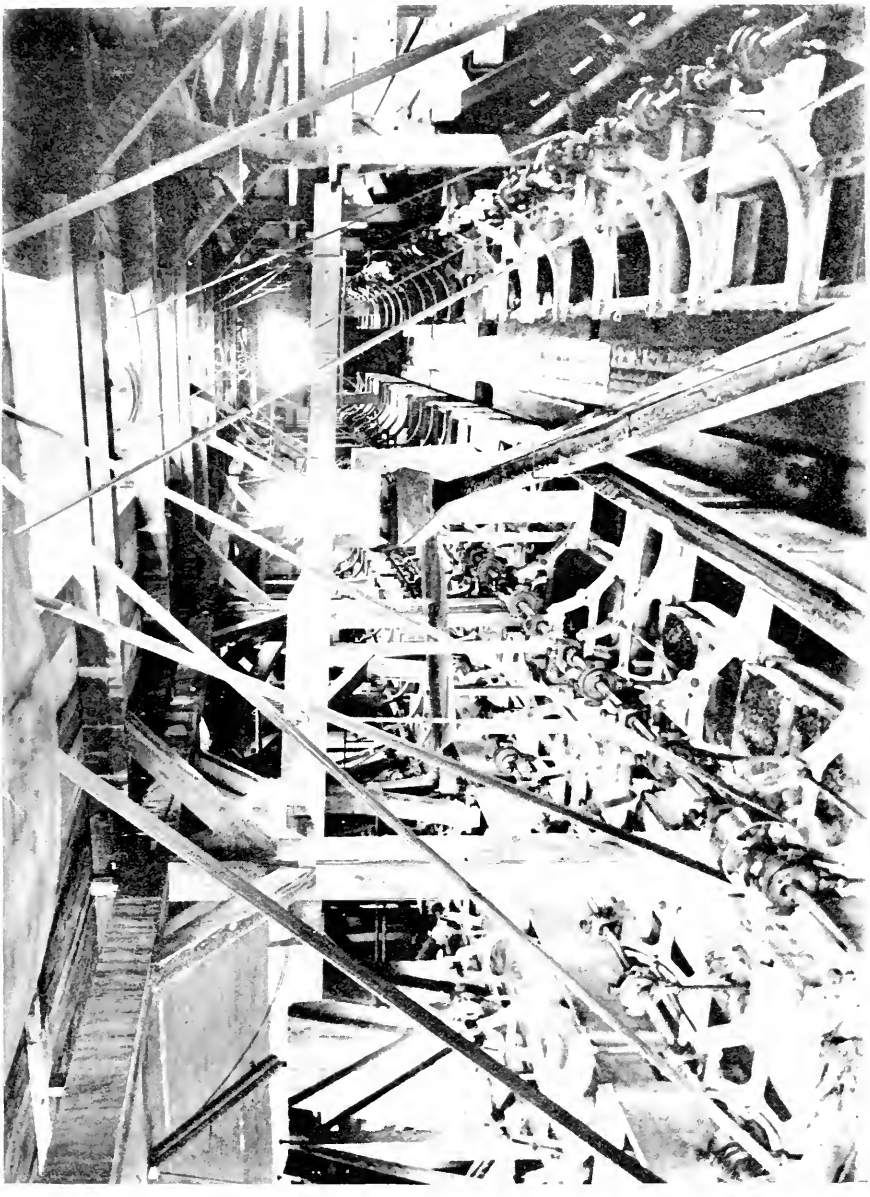

Fig. 306.—View of Interior of the Cwmystwith Concentrating Mill.

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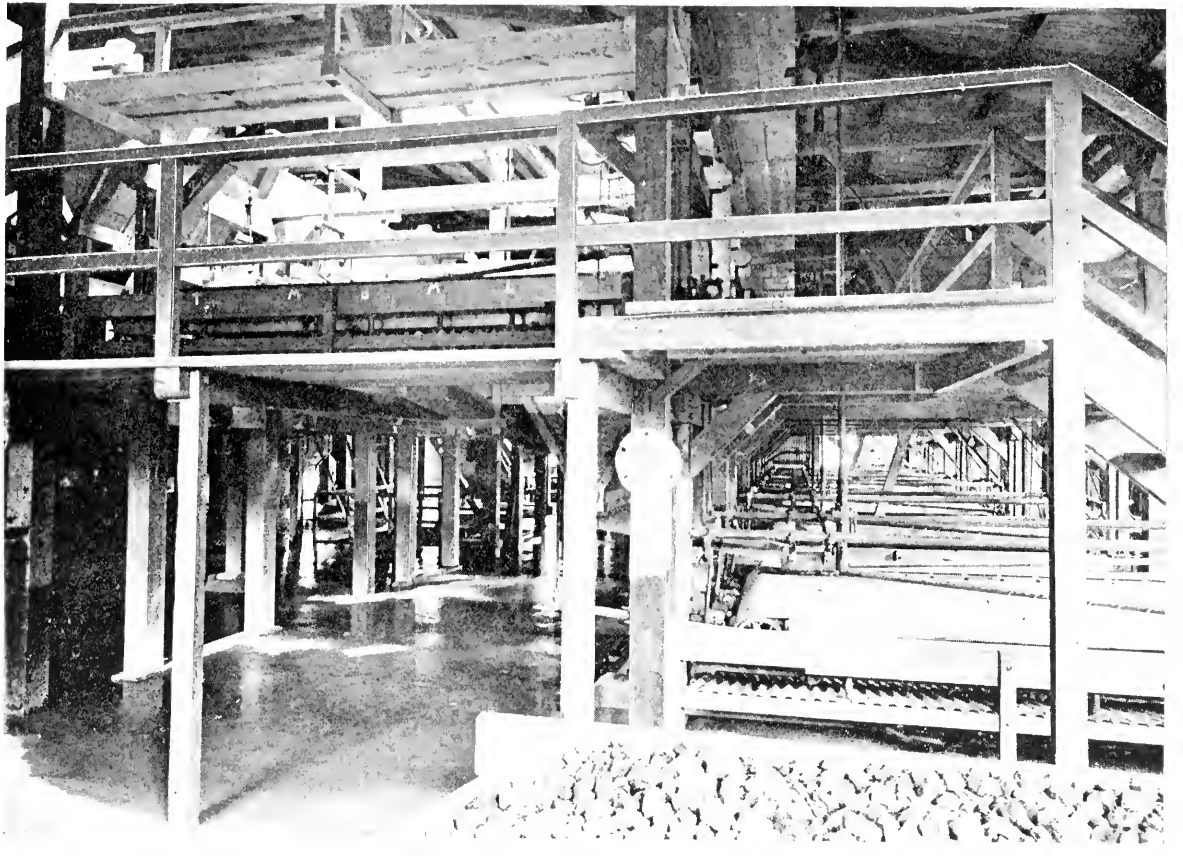

Fig. 307. The Upper and Lower Vanner Floors, Cwmystwith Concentrating Mill.

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band (7). It will thus be seen that at this stage the whole of the material is sorted into three classes, viz., that from $\frac{1}{2}$-in. and under which does not require further grinding and is ready for sizing; next, that from $1\frac{1}{4}$-in. to $\frac{1}{2}$-in. which is discharged on to the crushing rolls (5 and 6), and is here reduced to sizes below $\frac{1}{2}$-in.; and finally the sizes above $1\frac{1}{4}$-in. which go to the picking-band. On this they are hand-picked by boys who throw away the waste into hoppers on the lower floor, whence they are trammed to waste. The clean lumps of galena and blende are also picked out on this table and are deposited into separate receptacles.

The unpicked material remaining on the band which acts as a conveyer is carried on to a circular picking-table (18) on which the material is finally examined and picked over again.

The ore remaining on the table is now automatically scraped off, and falls into the large crushing rolls (9), the steel rollers of which have a diameter of 36 in. and run at a speed of 45 revolutions per minute. The larger lumps are crushed in these rolls, and falling into the main elevator (4), are lifted up together with the material from the roller mills (5 and 6) and the fines from the sorting trommel (3). The elevator (4), which has unperforated buckets, discharges the crushed material and slimes, first into the vibro-screen (12) which has three screens with 12, 5, and $1\frac{1}{2}$ mm. perforations. The object of this screen is principally to drain the muddy water and slimes containing fine material from the coarser sands, and to effect a preliminary sorting into three different classes before these are discharged separately into the classifying trommels (13, 14, and 15). This system has been found very advantageous, since the muddy water being drained off first does not flow into the classifying trommels, which thus get only clean grains for further sizing. The classification in the trommels, which are exceptionally large, is very perfect, and very clean grains are discharged into the jigs and this greatly assists the jigging process.

The ore rejected by the vibro-screens falls back to the rolls for recrushing, while the sizes between 12 and 5 mm. are discharged into the first trommel having 9 mm. and $6\frac{1}{2}$ mm. perforations. The sizes from 5 to $1\frac{1}{2}$ mm. flow into the second trommel which has 5 and $3\frac{1}{2}$ mm. perforations, while the fines below $1\frac{1}{2}$ mm. go straight to the spitzlutten.

The third trommel with $2\frac{1}{2}$ and $1\frac{1}{2}$ mm. perforations receives its charge from the second trommel. All classified grains now fall automatically and separately through shoots into the jiggers (10) which are of an improved Hartz type, each of which has four compartments 3 ft. long × 1 ft. 6 in. wide. The shafts of these jigs run in swivel bearings, and the products are discharged through a special sliding valve from the lower box. The speed of the jigs varies from 280 to 150 revolutions per minute, according to the sizes of the grains under treatment.

Clean lead concentrates are produced in the first compartment of each jig, and clean blende concentrates in the third.

The middlings from the second and fourth compartments of all the jigs are automatically discharged into the middlings elevator pit (16) on the lower floor; while the products ready for market are discharged into the concentrates hoppers (c), and these are trammed to the storage house.

The middlings from the jigs are now raised through the middlings elevator (16) and recrushed in the middlings or chat mill (17), from whence they are raised again by the elevator (18), and discharged into the vibro-screens and classifying trommels (19, 20, 21), where the classification takes place in the same manner as described before in the crude ore system except the perforations of the trommel screens are smaller.

Fine Sands and Slimes.—The fine sands below $1\frac{1}{2}$ mm. and the slimes flow from the classifying trommels, first into spitzlutten or hydraulic classifiers, and here the sands are separated from the slimes, which latter flow on into the large spitzkasten (s). The fine sands down to $\frac{3}{4}$ mm. are jigged on fine grain jiggers, the sands from the crude ore system being kept separate from those coming from the middlings system.

The whole of the slime waters are now thickened and the slimes classified in the large spitzkasten, from which the condensed pulp or slimes flow into distributing launders, and these discharge the proper amount of each class of slimes separately on to the Lührig vanners (22) on the upper floor. Here, again, clean lead and blende are made and discharged into product boxes. The lead and blende middlings from all the upper vanners are retreated on the lower range of vanners (23), and the middlings from these are returned for retreatment by means of the sand pump (24).

Tailings.—The tailings from all the jigs flow into the tailings hopper (t) on the lower floor, from whence they are trammed to the dump, while the fine slime tailings flow from the vanners to waste.

Results.—The following assays are from careful samplings of the concentrates and tailings taken while the mill was in full work.

Lead concentrates:	Coarse jiggers	76·33 % Pb.
,, ,,	Fine ,,	78·54 % ,,
,, ,,	Vanners	81·96 % ,,
Zinc concentrates:	Coarse jiggers	55·33 % Zn.
,, ,,	Fine ,,	57·54 % ,,
Tailings:	Coarse jiggers, Lead trace	1·26 % ,,
,,	Fine ,, ,,	1·22 % ,,
,,	Vanners ,, ,,	2·00 % ,,

General remarks.—The men required to work the plant are two at the stone-breakers, one on the trommels, one at the roller mills, three at the jiggers, and one man and three boys at the vanners. In addition to these there are the boys required at the picking-belt and the picking-table,

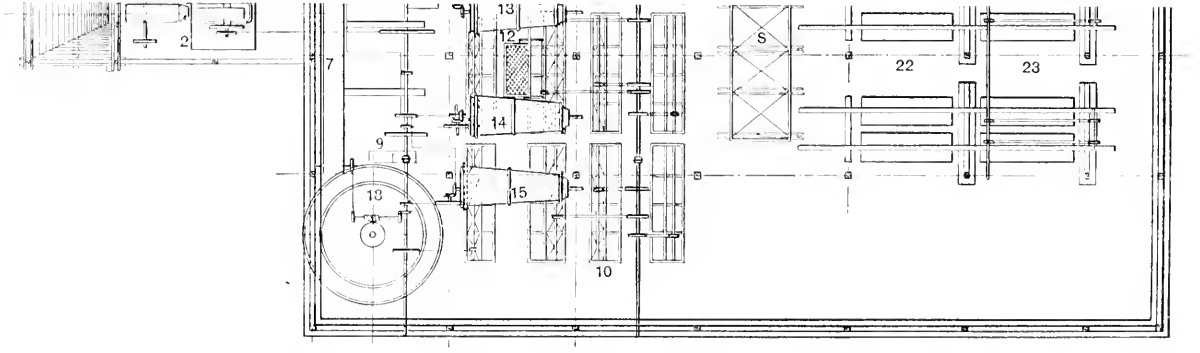

Fig. 308.—Plan and Section of the Cwmystwith Concentrating Mill.

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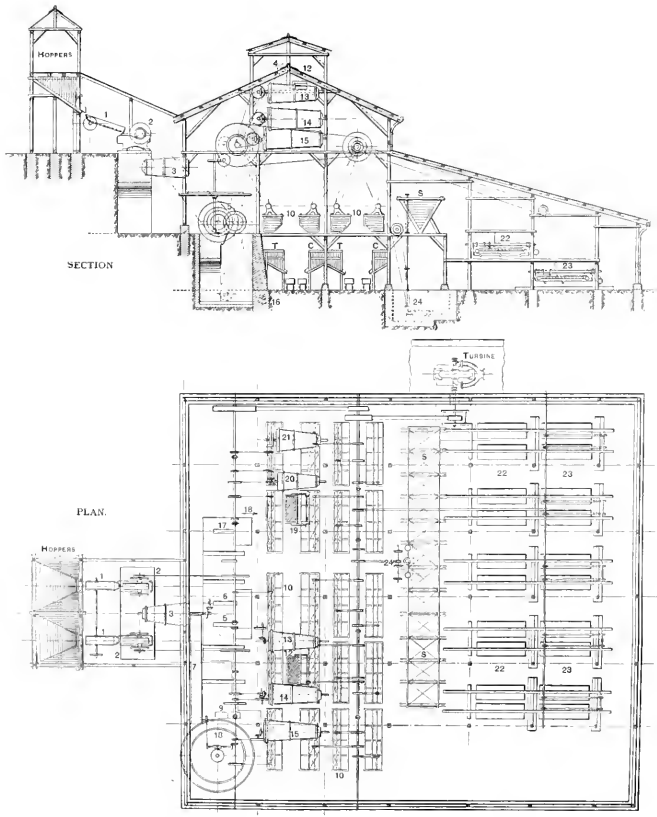


Fig. 308.—Plan and Section of the Cwmystwith Concentrating Mill

[To face page 458.

usually ten to twelve, but this can be varied according to the nature of the ore, which, when the mineral is finely disseminates, requires more careful hand-picking. Three men are also employed moving the tailings. When running at its full capacity of 10 tons an hour, the whole plant can therefore be worked by eight men and three boys, with, say, ten boys at the picking-table in addition. The plant, as was stated already, is driven by water power and absorbed 120 horse-power. As a reserve in case of drought a water gas-plant and gas-engines were also installed.

The whole arrangement being automatic, the milling costs were reduced to a minimum, and the whole mill worked to the entire satisfaction of the mining company, of which at the time I was the engineer.

Small Crushing and Concentrating Plant.—There are many mines which, from the nature of their lodes, or situation, or for financial reasons, cannot ever develop into large undertakings, and where, consequently, it would not be wise to put up the perfect (but somewhat expensive) plants just described.

For these small mines, especially where there is an abundance of water supply, a plant such as that illustrated in fig. 308 is perhaps the most suitable, although high-grade concentration must not be expected from it. This style of mill is in use in Wales, though unfortunately, owing to the fall in the value of lead, many of the mines at which these mills were erected are now lying idle. The ore as it comes from the mine is tipped over a kiln or bin, from which it is raked out at the lower end on to grates, where it is hand-picked over by women who take out the rich ore. The remainder is then spalled or broken up by hand, though now stone-breakers are generally used for this purpose, and then wheeled into the crusher-house on the left of the section (fig. 308A). Here it passes through rollers 26 in. diameter (A A) in the section, and shown provided with the old-fashioned lever arrangement for closing them up instead of the indiarubber buffers now in general use. Underneath the rollers is the sorting trommel (B) which separates the insufficiently crushed mineral and sends it back to the rollers by means of the elevator (*b*). The other mineral passes through a slime cone, which drives off the fine slimes, and then through the series of trommels (*c*, *d*, *e*) which classify it into sizes varying with the kind of ore and distribute it to the jiggers (C, D, E) by means of the chutes (*c*, *d*, *e*). The slime waters containing the fine grained mineral, pass over wooden, inverted cones (*f*, *g*, *h*) each having an upward current of water, and, after being thus classified, are treated in the jiggers (F, G, H). The fine slimes are enriched on the circular buddle (I) after a part of their excess of water has been got rid of in the settling tank or spitzkasten (K).

The jiggers are of three compartments, with the ordinary eccentric

motion as described on page 292, and the details of a buddle are shown in fig. 208 (page 303).

The whole mill is driven by a waterwheel, but there is no provision for recrushing the mixed ores, and the arrangement for treating the slimes is somewhat wasteful and expensive.

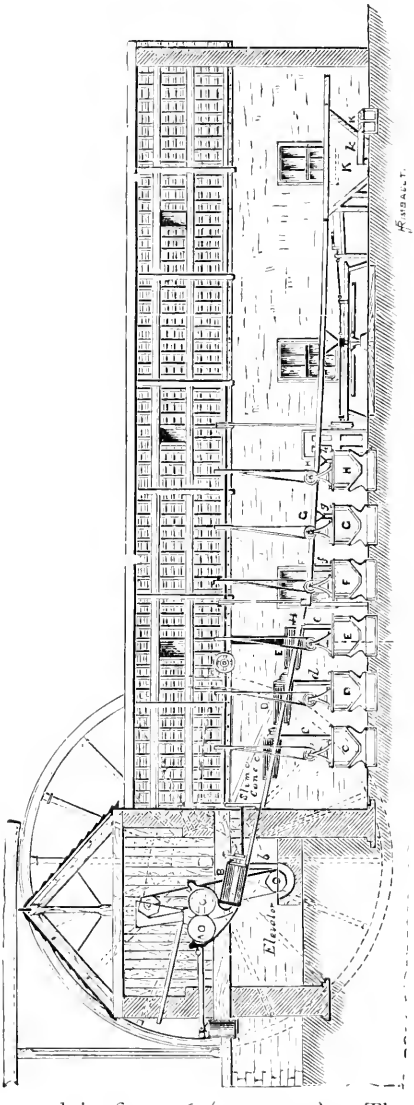


FIG. 308A.—SECTION OF SMALL LEAD CONCENTRATION MILL.

For small undertakings, however, the arrangement is not unsuitable, because of its simple and inexpensive nature; and if a stone-breaker, picking-table, and fine crushing rolls were added it would be much more economical, and recover a greater percentage of lead. Where possible two waterwheels should be employed, one for the crushing, and the other for the jigging machinery.

The slime waters, after leaving the wooden settling tank, are led through a series of slime pits, where any solid matter is deposited, which is afterwards dug out, and, if rich enough, put through the buddles again being first well mixed up with water in a stirring machine called a "devil," such as that illustrated in fig. 207 (page 302).

Before the introduction of the perfect machines of the present day, the dressing of lead ores was conducted largely by hand with home-made machines, such as the hand-jigger shown in fig. 197 (page 292), which superseded the use of sieves for jigging, the use of which is illustrated in fig. 196 (page 291). The crushed ore was roughly or not at all classified into sizes before being thrown into the sieve of the jigger, which is suspended by the iron rods (*a a*). The woman then works the lever (*b*) up and down, and this rocks the lever (*c*) from

which the sieve is hung, but owing to the play allowed at the joint (*c*) a blow is struck at each stroke of the jigger, which assists the separation of the rich from the poor ore. The rich ore forms itself in a layer at the bottom of the sieve, covered with a layer of mixed ore and steriles. The slime waters run across settling tanks, from which the slimes are dug up and treated on a flat or a round buddle.

In some of the small plants in Wales which are usually of the type just described, a second pair of rollers has been added for recrushing the jigger tailings and tables of the Wilfley or the Lührig type have been added. The slimes, however, are very generally treated on buddles, as owing to their cheapness they appeal to the owners of small mines, though the cost of labour in working them is usually lost sight of.

Caution Required in Adopting New Processes.—The history of the development of the machinery at present in use from the crude appliances of the past would be of great interest, but in this work, which is devoted to the modern appliances of mining, I can make but the short reference to them which I have just given.

I may, perhaps, at this point, utter a word of warning against the unreasoning and hasty adoption of a process because it happens to be new. It is useless hiding the fact that many mining companies have been ruined, without any reference to true character of their mines, through men who have no knowledge of the business in hand deciding on the utility of new processes or machinery. It is often assumed, that if an inventor or manufacturer of new machinery will agree to guarantee success, or to take no pay if not successful, the company takes no risk. In actual fact, a whole year is wasted in most cases, failure spoils the reputation of a company, running expenses have continued, and further working capital cannot be raised, because all concerned have lost confidence by the failure to obtain the returns promised. All this in addition to the regular, unavoidable risks of mining itself, which may, at any moment during the year lost, call for increased expenses, and increased faith in ultimate success.

To the mining man who makes money by the business, the natural risk of mining is all he will take : that in itself is sufficient ; and when he invests more money in machinery he takes good care that he takes no chances either failure or delay. (As to losses in concentration see *post*, page 474.)

After the mine has become a dividend-paying property, then a few experiments may be indulged in without materially affecting the shareholders' pockets, but until then both manager and directors alike should be prohibited from wasting the shareholders' money, and courting disaster, by running after new and untried methods of crushing, concentration, or amalgamation. A thoroughly experienced manager will not need to be reminded of this, nor will he risk his reputation by speculating in improvements which may probably jeopardise the success of the undertaking.

CHAPTER XXVI.

OTHER METHODS OF CONCENTRATION—THE WORKING OF MILLS, ETC.

The Elmore Oil Process—Magnetic Ore Separation—The Monarch Magnetic Ore Separator—The St. Lawrence Iron Sands—Results of Magnetic Ore Separation—The Working of a Concentration Mill—Data—Power and Water required for various Mills—Belting—Losses in Concentration—Percentage saved.

The Elmore Oil Concentration Process.—Students of the art and science of ore concentration are usually and wisely warned to prevent any oil or grease from the bearings getting mixed up with the ore under treatment; and yet in this oil concentration process we have highly successful results obtained from the deliberate introduction of oil. The process, as it is now being worked at the Glasdir Copper Mines at Dolgelly, North Wales, may be shortly described as follows.

The rock from the mine, after passing through the usual stone-breakers, is crushed in a pair of Cornish rolls, and run thence to two Huntington mills, wherein it is reduced to pass through a 30-hole screen, and issues therefrom with just sufficient water to make it into a freely flowing pulp. From the Huntingdon mills the pulp passes directly into the open end of a horizontal rotating drum, inside of which is fixed a helix with cross blades or buckets, which lift up the pulp to a certain height and drop it again, at the same time propelling it forward to the opposite end of the drum, thus keeping the pulp in constant agitation for the few seconds which are occupied in its progress through the drum. With the pulp is also admitted a small quantity of a thick, sticky oil (the residue left in the stills in the refining of paraffin oil). This oil is, of course, subjected to the same agitation as the pulp, and is consequently tumbled about with it, and exercises the remarkable property of sticking to and buoying up the particles of minerals that are floating about or suspended in the pulp; but it does not stick to or have any effect whatever upon the particles of rock which are present in much greater number. The oil and pulp automatically discharge from the opposite end of the drum into a pointed box or spitzkasten, in which the tailings or rock at once settle down and flow off with the water at the bottom

whilst the oil, by reason of its buoyancy, floats to the top and carries up with it practically all the values which the ore contained.

From the pointed box the oil with its load of mineral flows off continuously to a specially constructed centrifugal machine, where the oil is extracted from the mineral (which is left in the machine), and is at once ready for re-use. For close extraction three mixing cylinders are used, the pulp passing from one to another after floating off the oil and collected mineral and receiving a fresh stream of oil in the next mixer. A second centrifugal machine is also found desirable below the first, to more perfectly separate the oil and water from the concentrates. The concentrates are left in the machine, dry and almost free from oil.

The illustration (figs. 309, 309A, Plate XXI). shows the general arrangement of the plant adopted, and from the successful nature of the trials made with samples of ore from all over the world it is not too much to say that the process has a great future, particularly in cases of difficulty by water concentration arising from brittleness or lightness of minerals to be separated, or from heavy gangue accompanying the minerals, such as heavy spar, magnetite, garnets, rhodnoite, etc. It does not seem to matter how finely the mineral breaks; if it is a mere scum on the water surface, contact with the oil in the agitating cylinders and recovery of the float values appear to be assured. Where water is scarce the process has a great advantage, for the rock can be crushed with the minimum quantity used in regular wet stamping, and by settling can be used over again, as a little muddiness of the returned water is no disadvantage.

In practice it has been found at Glasdir that very little attention is required for the control of the process; that considerable variations in quantity of oil supply and temperature are allowable; and unskilled labour can be used under the superintendence necessary in any mill. The plant is much simpler than that of an ordinary concentration mill; is not expensive to instal; is subject to little or no wear and tear, and can be put below any wet crushing machinery. In existing mills where heavy loss in slimes occurs this process can be easily added as an auxiliary plant. Material as coarse as 20 mesh has been concentrated.

The loss of oil has been found to be at Glasdir 1¼ gallons per ton of ore treated, and may be taken as varying according to ore and other conditions, between 1 and 3 gallons per ton. The oil is of a very cheap class.

The concentration appears to depend on the surface condition of the material; and generally it may be said that metallic surfaces are attachable to the oil, and earthy surfaces not. Nevertheless, sulphur, earthy-looking cinnabar, graphite, molybdenite, and some other minerals, which in advance might not seem to possess promising surfaces, are most successfully taken up by the oil. Tellurides which are difficult

to concentrate, and from their gold and silver values need close saving, are easily concentrated. Some oxidized gold ores in which the metal is so fine as to defy amalgamation have given good results. Average banket gold ore from the Randt mines without any previous amalgamation has yielded a high extraction and rich concentrate. These last three classes would seem to promise a field for the process in direct competition with cyaniding.

I have seen experiments made with this process, and also seen the concentrates and tailings produced from other trials. It is indeed difficult to believe, unless one has actually witnessed the experiments, that the oil coats the mineral particles sufficiently to enable them to float to the surface and leaves the particles of gangue untouched, and reversing the lever of specific gravity at the bottom. With this, as with all other processes, it is well in the first place to make exhaustive trials to prove its applicability or otherwise to any given ore, and for this purpose the owners are willing to place their trial plant at the service of engineers in all cases where difficulty or loss occurs in existing methods of concentration or cyaniding.

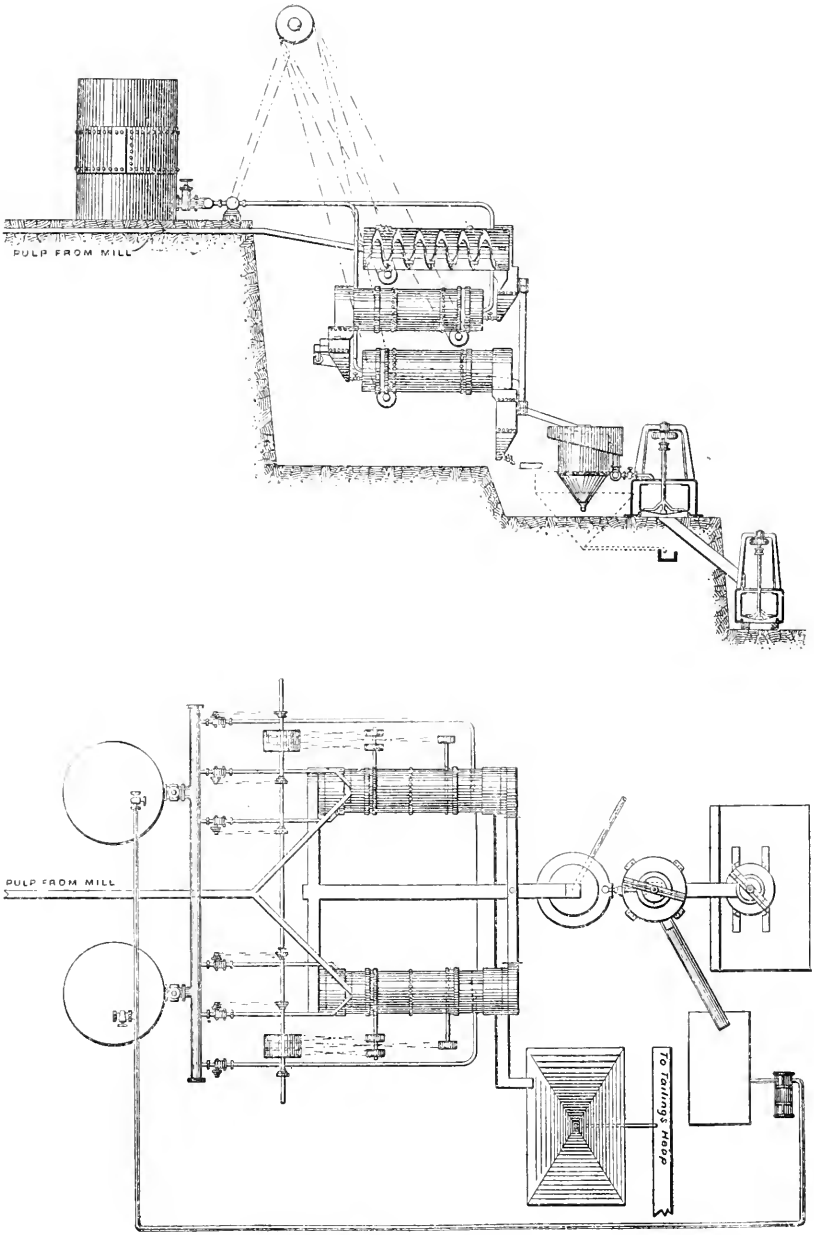
Magnetic Ore Separation.—Magnetic concentration has lately become an important industry in the United States.

Although the application of magnetism in the treatment of magnetic ores is not novel, it has not till within the last two or three years been looked upon as capable of successful demonstration on a commercial scale. The universal scepticism which prevailed regarding the practicability of this method arose from a variety of causes.

Through the kindness of Mr. A. T. Porter, I am enabled to give a description of the "Monarch" magnetic ore separator. Before going into details, however, I shall give a few facts which may be of general interest regarding the earlier efforts, difficulties, and progress of this industry.

More than fifty years ago machines were constructed and patented for the purpose of concentrating the magnetic iron sands of the St. Lawrence and other places, but further than that the patents set forth this fact, little is known how far they were successful. However, that they were not commercially successful, their non-existence at present would indicate; nor is this result to be wondered at when we consider that the successful treatment of this material is the most difficult problem in magnetic concentration.

The St. Lawrence iron sands vary from 10 to 50 per cent. of magnetite, and from 5 to 15 per cent. of titanium, a large proportion of this latter being also magnetic, and as the presence of over $2\frac{1}{2}$ per cent. of titanium in the concentrate depreciates to a great extent the value of the ore, not only has the magnetic to be removed from the non-magnetic, but the two magnetic substances have to be separated.



Figs. 309, 309a.—The Elmore Oil Concentration Plant.

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How difficult this latter is, especially on a large scale, can be readily appreciated when we consider the extreme fineness of the material, and that it is impossible to distinguish any difference between the titaniferous and non-titaniferous particles, even with the aid of a powerful glass, and as both readily respond to magnetic influence, it is only by the combined use of a hand-magnet and glass that a slight variation in their magnetic susceptibility can be discovered.

The Monarch machine is capable of such fine adjustment that it will take advantage of this slight difference, and so affect the separation of the titaniferous from the non-titaniferous particles on a successful commercial scale, as will be seen from the analytical table on page 468, drawn up from assays made by Mr. Riley. The small amount of middlings made and the large percentage of titanium it contains shows clearly the efficiency of the separator.

It is at present thought that the titanium remaining in the concentrate is evenly distributed through the whole mass. Should this, however, prove not to be the case, we may look for a yet further reduction of titanium in the concentrate.

The success of this process is doubly important, for not only are there large deposits of these iron sands in different parts of the world, but there is also a large opening for such a machine for the treatment of auriferous iron sands, as well as the zinc ores containing magnetic iron.

The concentration of rock ore has also occupied the attention of inventors and investors for a great number of years, and it is no exaggeration to say that for this purpose hundreds of patents have been obtained in various countries.

At first the object sought was to increase the percentage of iron in the ore. Such was the case in a Swedish mine where the leaner portions of the ore were piled on waste dump, until the rich veins had in a measure become exhausted, when women and children with hammers were employed to detach and pick out the richer portions of these waste piles. What is known as a direct contact machine (in which the ore comes in direct contact with the magnets), was invented and substituted for this naturally slow and uncertain method, and with comparatively favourable results; but although this machine has been used for several years for "cobbing" purposes, there seems to have been no effort made to improve it, so as to meet the more critical requirements of ore concentration. Several attempts were made, and a large amount of money expended to utilise the vast deposits of titaniferous rock ore in the northern part of New York State, all of which resulted in failure, owing, it has been stated, to the titanium being too closely associated, and evenly distributed through the entire mass of the ore. How far the inefficiency of the separators used contributed to the

failure of the enterprises is a question which can only be determined by an application to these ores of the latest improved methods.

To the development and extended use of the Bessemer process may be attributed much of the wonderful progress recently made in magnetic concentration, creating as it does a demand for ores low in phosphorus and sulphur, although the brisk competition in the iron business also created a demand for the higher grade of ores.

The illustration (fig. 310) represents a longitudinal section of the Monarch magnetic ore separator, the joint invention of Mr. Sheldon Norton, of Hokendangua, Pa., and Messrs. C. M. Ball and A. T. Porter, of Troy, New York, U.S.A.

The apparatus consists of a partially closed chest, having an opening

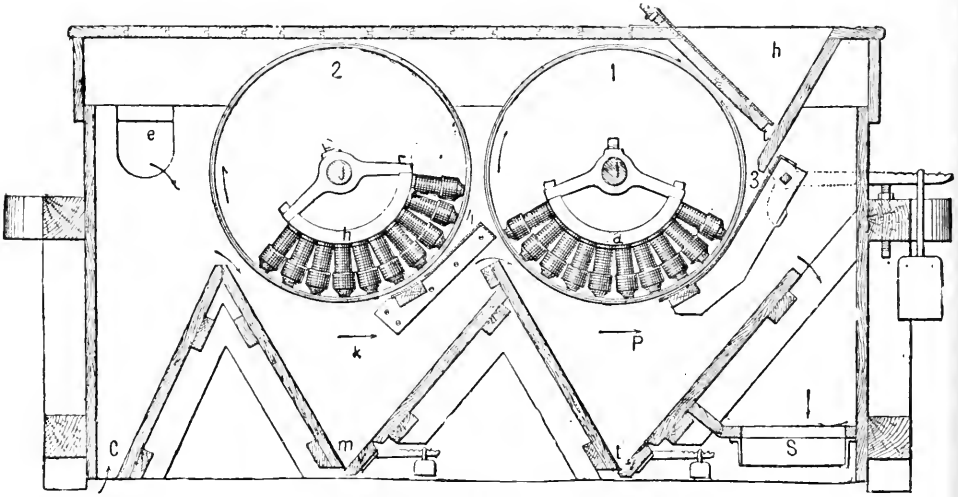


FIG. 310.—THE MONARCH MAGNETIC ORE SEPARATOR.

at *f* from the feed-hopper (*h*) through which the ore is delivered to the machine from an ore pocket or storage-bin, provided with means for regulating the flow of ore so that when the machine is in operation the hopper is kept always full. Other openings are provided for the discharge, at *t* of tailings, at *m* of middlings, and at *c* of concentrate; also at *e* for allowing free ingress of air to the chest at that point, and at *s* where a powerful exhaust fan is connected. The openings at *t* and *m* are kept sealed against ingress of air, at those points by means of the hinged and weighed valves, *v v*, which discharge the products from the hoppers, *p* and *k*, continuously, and in the same proportion as received from above, when a sufficient weight has accumulated upon the inside to cause the contents of the hoppers to leak by the valves.

When the machine is in operation the brass drums, 1 and 2, revolve

on shafts, *i* and *j*, in the direction of the arrows, the magnets and shafts being stationary. The magnets are so constructed that the poles alternate, so that when the ore passes from hopper, *h*, along apron, 3, it comes under the influence of the magnet, and is picked up and firmly held against the drum; and as the drum revolves the ore is forced along past a succession of alternating poles, so that the magnetic particles take on a rotating or tumbling motion, allowing the non-magnetic gangue which may be entangled to be thrown off into hopper, *f*, while the magnetic portion is carried on and transferred to drum, 2; this drum revolving at a higher speed than the other throws off the less magnetic portion of the ore, this product being termed middlings, while the refined ore is carried to the end of the magnetic field, and delivered at *c*. The middlings consist of particles of magnetite having small pieces of rock or other foreign substance attached, and the proper regulation of this product is one of the important features of the invention; in fact, in some cases being vitally so, as in the cases of the sand ore, where the foreign substance is titanium.

An improvement in the magnets has lately been made by Mr. Porter which gives a uniform magnetic field outside the drums, so that as the ore turns over on the first drum it not only allows the gangue to be expelled, but the richer portions of the ore get close up to the drum, while the leaner portion works to the outside of the stream, and this relative position of the particles being maintained during the transfer to second drum, the less magnetic material (middlings) is the more readily thrown off. A very important saving in the crushing of rock ore can be made by this perfect control of the middlings. For instance, if the ore contained 5 per cent, of phosphorus, if there were only two products, concentrate and tailings, it might be necessary to crush the whole of the material to 16- or 20-mesh to get the iron sufficiently free from the rock (as the rock, in magnetic ores invariably carries the phosphorus); but if separated by the Monarch it could be taken, say at 6- or 8-mesh, when a large percentage of the pure iron could, be recovered, and much of the worthless rock discarded, the middlings, representing probably 15 to 25 per cent. of the whole, alone requiring further crushing, not only saving the cost of crushing, but the even more objectionable feature of very fine ore. Consequently, by regulating the speed of the second drum, the concentrate can be brought to any degree of purity required—the greater the speed of drum the larger the percentage of middlings thrown off.

Space will not permit more than to draw attention to the great importance of this process in the treatment of zinc, silver, gold, tin, and other ores where magnetic ore may be present, or, indeed, any form of iron capable of being made magnetic by roasting.

The following are the results of a trial of this machine upon the

ferriferous sea sand of the St. Lawrence, and show the analyses of the ore before and after concentration as well the weight of the various products :

ST. LAWRENCE SEA SANDS.

No.		Iron.	Titanium.	Percentage of Total Weight.
1	Crude	59·32	11·51	—
	Concentrates . .	69·40	2·37	52·50
	Middlings . . .	59·93	11·80	3·75
	Tailings . . .	47·68*	23·42	43·75
2	Crude	52·32	11·51	—
	Concentrates . .	69·75	2·69	51·87
	Middlings . . .	59·98	11·97	1·87
	Tailings . . .	—	—	46·26
3	Crude	55·20	4·50	—
	Concentrates . .	70·75	1·50	51·00
	Middlings . . .	56·50	11·69	0·75
	Tailings . . .	—	—	48·25

A machine of a somewhat similar nature is made by Messrs. Sautter Harle & Co., of Paris, and has been supplied by them to several mines in Germany where the ore is a mixture of zinc and carbonate of iron. In treating this ore the concentrates are first roasted in order to make the iron magnetic, and then passed over a series of magnetic separators until the iron has been quite eliminated. A more recent machine of this class is the Wetherill, which has been brought prominently before the public, and has been very successful in separating ores when the amount of magnetism was extremely small.

I have had considerable experience with the separation of magnetic iron from galena and blende at the Pierrefitte Mine in the French Pyrenees.

The machine employed there is very similar to that shown in fig. 310 except that there is only one copper drum revolving around the fixed electro-magnets. At first the practice was to dry the blende concentrate containing some 15 to 20 per cent. of magnetite, and then feed it in a dry powdery state over the machine. This was very successful and reduced the amount of iron to less than 3 per cent., but the cost of drying and handling the ore was very heavy on an ore of low value such as blende. I therefore instituted a long series of experiments, and finally succeeded in treating the slimes in an absolutely wet and fluid state ; in fact I inserted the machine between the spitzkasten and the vanners it was feeding. A perfect separation resulted and the machine reduced the iron to under 3 per cent., leaving the slimes much more easy to concentrate on the vanners.

* Non-magnetic iron.

The specific gravity of magnetite is practically the same as that of blende, so that its separation by the ordinary process of concentration was impossible. By getting rid of it before concentration the problem of separating the lead and the blende was solved and clean concentrates obtained direct. The voltage of the current used was 750, and of course special precautions had to be taken with the insulation, especially in view of the fact that the drum was immersed in water, but this after a few breakdowns was overcome.

While the amount of iron in the blende was reduced to under 3 per cent. there was a similar percentage of blende in the iron. This it was found impossible to prevent, as the iron particles on the drum acted as brushes and carried a little blende over with them into the iron compartment.

The Working of a Concentration Mill, and Mill Data.—The secret of success in running a concentration mill lies much in procuring a well-trained and competent manager; for the business of concentration needs as much education and skill as that of the refining and smelting of ores. I have known a case in which a first-class modern concentrating plant for treating lead and blende ores was entrusted to a man whose only knowledge of engineering was in connection with steamers and marine engines. Needless to say that failure resulted, and the tailings were as rich as the crude ore. In another case I knew of a first mate of a steamer being put in charge of a gold mine and mill, with a result which may be anticipated. It is just as necessary to put fully qualified men in charge of milling machinery as it is to put a qualified medical man in charge of a hospital; though the grave error of putting amateurs or relatives of directors of a mining company to look after the most costly and intricate machinery is continually being made.

In designing a mill it is most important to have a sufficient fall for all the launders and screens, in order to prevent the stream of ore from becoming blocked, and thus also minimise the quantity of water necessary.

Plenty of light, plenty of room, plenty of water, and an excess of power are essentials. With insufficient power it is impossible to keep up a regular speed, stoppages and blocks will be frequent, and the whole of the concentrating machinery will work at a great disadvantage. Mix the ore from the various parts of the mine so as to keep up an even standard of crude ore and assay this, the concentrates, middlings, and tailings, constantly so as to keep a check on the work done and the results obtained. As to the losses in concentration, these will be referred to on page 474 following.

The following general data relating to the concentration mills will be found useful:

Power in Concentrating Mills.

The amount of power required to run a concentrating mill will vary according to the size of the mill, or about as follows:

15 to 30 tons daily capacity, power needed about $1\frac{1}{2}$ horse-power per ton treated.
50 to 75 tons daily capacity, power needed about $1\frac{1}{4}$ horse-power per ton treated.
100 to 120 tons daily capacity, power needed about 1 horse-power per ton treated.
200 tons daily capacity, power needed about $\frac{3}{4}$ horse-power per ton treated.

Water.

The amount of water required per ton treated will average about 700 gallons, inclusive of the water used for steam power. In badly constructed mills this often runs up to 1000 or even 2000 gallons per ton treated. If ample settling tanks are provided, and the water is allowed to settle, and is then pumped back and used over, the amount per ton can be reduced to 200 gallons.

Cost.

In Colorado the cost of concentration in well-equipped mills averages as follows:

20 to 30 tons daily,	$1·50.	Approximate cost of the mill,	$ 5,000 to $ 8,000.
40 to 50 tons daily,	1·00.	Approximate cost of the mill,	8,000 to 13,000.
75 to 100 tons daily,	·75.	Approximate cost of the mill,	12,000 to 18,000.
150 to 200 tons daily,	·60.	Approximate cost of the mill,	20,000 to 30,000.

Capacity of Rolls and Screens.

The capacity of a set of rolls depends largely on the evenness of the surface. If the rolls are worn corrugated, so that they do not meet, except in spots, their efficiency is reduced, oftentimes as much as 50 per cent.

A set of well-constructed 14 × 27-in. rolls, with even surfaces, and running at 100 revolutions per minute, will reduce ordinary quartz ores as follows, taking the ore from the crusher at $\frac{1}{2}$ in. size:

To 8-mesh screen size,		3500 to 4000 lb.	per hour.
,, 12-	,, ,,	2500 ,, 3000 ,,	,,
,, 15-	,, ,,	2000 ,, 2500 ,,	,,
,, 20-	,, ,,	1500 ,, 1800 ,,	,,

The capacity of rolls from a scientific point of view is also dealt with on page 254, and illustrated in the diagrams 163A, 163B, 163C (Plates V., VI., VII.).

The ordinary type of round or hexagonal screens or trommels, such as in fig. 185 (page 279), running at 20 revolutions per minute, can be depended upon to screen as follows per square foot of screen surface:

8-mesh size,	per hour,	100 lb.	
12-	,, ,,	80	,,
16-	,, ,,	65	,,
20-	,, ,,	50	,,

In dry screening the quantity would be somewhat greater, but as the capacity of both rolls and screens varies with the kind of ore, the above figures are only approximate.

Power Required to Drive Crushing Mills.—The amount of water power available at or near a mine will often decide the size of the mill to be erected. In any case, whether the mill is to be driven by water, steam, or electricity, one of the important points is the horse-power which it will take to drive it, and the results in tons treated which may be reasonably expected from the expenditure of that power.

The following tables will enable an approximate estimate to be formed on these matters, and also show the power required to drive each of a standard type of machine, from which that necessary to work a number of the same machines can be calculated :

POWER REQUIRED FOR A 10-STAMP WET CRUSHING GOLD MILL.

1 "Blake" rock-breaker, No. 2	=	6 horse-power.
2 ore feeders	=	0 ,,
10 stamps, 750 lb., 90 drops	=	12 ,,
4 Frue vanner concentrators	=	2 ,,
1 grinding pan, 3 ft. diameter	=	3 ,,
1 settler	=	3 ,,
Friction	=	4 ,,
Total	=	30 ,,

Capable of working 15 to 18 tons per day of 24 hours.

POWER REQUIRED FOR A 20-STAMP WET CRUSHING GOLD MILL.

1 "Blake" rock-breaker, No. 2	=	6 horse-power.
4 ore feeders	=	0 ,,
20 stamps, 750 lb., 90 drops	=	23 ,,
8 Frue vanner concentrators	=	4 ,,
1 grinding pan, 8 ft. diameter	=	3 ,,
1 settler	=	3 ,,
Friction	=	7 ,,
Total	=	46 ,,

Capable of working 35 to 40 tons of ore per day of 24 hours.

POWER REQUIRED FOR A 10-STAMP WET CRUSHING SILVER MILL.

1 "Blake" rock-breaker, No. 2	=	6 horse-power.
2 ore feeders	=	0 ,,
10 stamps, 750 lb., 90 drops	=	12 ,,
6 grinding pans, 5 ft. diameter	=	30 ,,
3 settlers, 8 ft. diameter	=	9 ,,
Friction	=	7 ,,
Total	=	64 ,,

Capable of working 18 to 20 tons of ore per day of 24 hours.

POWER REQUIRED FOR A 20-STAMP WET CRUSHING SILVER MILL.

1 "Blake" rock-breaker, No. 2	= 6	horse-power.
4 ore feeders	= 0	,,
20 stamps, 750 lb., 90 drops	= 23	,,
12 grinding pans, 5 ft. diameter	= 60	,,
6 settlers, 8 ft. diameter	= 18	,,
Friction	= 13	,,
Total	= 120	,,

Capable of working 40 tons of ore per day of 24 hours.

Allowance is made for grinding in the pans in both of the above cases.

POWER REQUIRED FOR A 10-STAMP DRY CRUSHING SILVER MILL.

1 "Blake" rock-breaker, No. 2	= 6	horse-power.
2 ore feeders	= 0	,,
10 stamps, 750 lb., 90 drops	= 12	,,
1 "Howell-White" furnace, 40 in.	= 4	,,
4 amalgamating pans, 5 ft. diameter	= 8	,,
2 settlers, 8 ft. diameter	= 6	,,
Friction	= 9	,,
Total	= 45	,,

WATER REQUIRED FOR A QUARTZ MILL.—The quantity of water required to work either gold or silver ores by wet battery process is generally estimated as follows:

For boiler, $7\frac{1}{2}$ gallons per horse-power per hour.
For each stamp, 72 gallons per hour.
For each pan, 120 gallons per hour.
For each settler, 60 gallons per hour.
Frue vanner, about 90 gallons of fresh water.

If the water used in the battery, pans, and settlers be run into settling tanks it can be re-used with a loss of about 25 per cent.

Belting.—At the commencement of operations with a new mill, one of the most frequent sources of stoppage and discord will be due to the stretching of the belts. It will, indeed, take some considerable time for them to attain their final fixed length beyond which they will not stretch, and until this point is reached it is better to make the joints with screw fastenings, which can be readily undone and refixed, instead of the more permanent lacing, which can be finally adopted.

Leather belts are useless in wet situations, where indiarubber must be used. With a given tension a leather belt will transmit 30 per cent. more power when the grain or smooth side of the leather is turned next the

pulley than when the flesh side is in contact with it. The belts should be kept soft and pliable by the application of tallow and neatsfoot or liver oil, with a little resin, when they become hard and dry. Their adhesion is greater on polished than on rough pulleys, and is about 50 per cent. greater on a leather-covered one than on a polished iron pulley.

The width of the belt should be determined by the strain to which it will be exposed, as the question of slipping is not affected by that of width. Long belts are more effective than short ones, and the slack of the belt should always be uppermost. Vertical belts depend entirely upon their tension, which the weight of the belt does not increase, as is the case with belts more or less horizontal.

At a velocity of 1000 ft. per minute a single belt, 1 in. wide, will transmit 1 horse-power, and a double belt will do the same at 700 ft. per minute; though when it is a long one, and running over large pulleys, it may be calculated to give 1 horse-power at the lower speed of 500 ft. per minute.

The strain which a good average leather belt may be calculated to withstand is 350 lb. per square inch of section; and at a speed of 1000 ft. per minute a section of 0·2 of a square inch will be required for each horse-power when the belt runs over a wooden drum. For smooth iron pulleys this must be increased to 0·4 of a square inch for each horse-power.

It must be remembered that grease and animal oil are ruinous to indiarubber belts, which when they show a tendency to slip should be smeared with boiled linseed oil on the inside, over which fine powdered chalk may be sprinkled.

The following rules will be found useful for various calculations relative to belting and pulleys:

To Find the Length of Belts.—Add together the diameter of the two pulleys, multiply by $3\frac{1}{8}$, and divide the product by 2. To the quotient add twice the distance between the centres of the shafts and the product will be the required length. Allowance must be made for the length of the lap of the joint.

To Calculate the Power of Belting.—The horse-power of any belt equals its velocity per minute in feet multiplied by its width in inches, and divided by 1000 for single, or by 700 for double belts.

The basis of this calculation is that 1 horse-power is transmitted by a single belt 1 in. wide travelling at a speed of 1000 ft. per minute, or a double belt of the same width at a speed of 700 ft. per minute.

To Find the Speed of Pulleys.—(*a*) When the diameter of the driven pulley is given to find the number of its revolutions:—Multiply the diameter of the driver by the number of its revolutions, and divide the product by the diameter of the driven. The quotient will be the number of revolutions of the driven. (*b*) To find the diameter of the driver to give a fixed number of revolutions per minute when the diameter and speed of the

driving pulley is known: Multiply the diameter of the driver by the number of its revolutions and divide the product by the number of revolutions desired for the driver. The quotient will be the diameter necessary for the latter. (*c*) To ascertain the diameter of the driver: Multiply the diameter of the driven by the number of revolutions desired and divide the product by the revolutions of the driver. The quotient will be the diameter of the driver.

Losses in Concentration.—The conduct of the various washing processes employed in the concentration of the ores of lead, copper, zinc, and tin requires constant watching, in order to prevent losses, not only by the carrying of mineral matter away with the steriles, but also from enriching the mineral beyond the economic point, at which concentration must cease, or loss be entailed from the washing away of the silver usually associated with these ores.

A system of sampling and assay must therefore be devised, and regularly followed throughout the various machines. The first point is to get an exact idea as to the quality of the ore as it arrives from the mine, and this can best be done by sampling the crushed ore as it passes from the first rolls or stamps to the first series of trommels, either automatically by a machine, or by hand. In the latter case one of the foremen in the mill can take a small boxful every half-hour, and put it into a case kept on purpose. From this case or box the assayer can take his sample at the end of the day.

The result obtained is given in percentage or units of metal, but care must be taken not to confound these two expressions. Let us assume that the crude ore contains 10 per cent. or 10 units of lead, or, in other words, that it will require 10 tons of the ore to yield 1 ton of lead. Now if the loss which is found in the tailings from the mill is $2\frac{1}{2}$ units, it must not be expressed as being $2\frac{1}{2}$ per cent., which would imply that only $2\frac{1}{2}$ units, were lost in every 100, but distinctly as units, meaning that out of the 10 units of lead in every ton of crude ore $2\frac{1}{2}$ units, or one-fourth of that amount, was lost, which would indeed be of a very appreciable value, and point to gross carelessness or unsuitable machinery somewhere.

In calculating the quantity of a metal contained in a pile of ore, or the probable milling result to be obtained from treating a given quantity, the assay of the crude ore is the basis. Let us assume that it is desired to know what dressed mineral may be obtained from a pile of, say, 200 tons of crude ore assaying 5 per cent. Pb. The total number of units of lead in this pile would be $200 \times 5 = 1000 \div 100 = 10$ tons of metallic lead, or, if there is no loss in dressing, 20 tons of 50 per cent. ore. But there is always some loss in the milling operations, and the probability is that the tailings from the mill will contain from $\frac{3}{4}$ to

1 unit of lead per ton, and the loss in dressing is the difference in quantity of metal present in the crude ore, and that found in the dressed product, as, for example—

200 tons crude ore of 5 per cent. Pb. = 1000 units.

When dressed yield

16·4	tons dressed ore of	50 per cent. Pb.	=	820 units.
183·6	,, tailings of	0·97 ,,	,, =	180 ,,
200				1000

The loss being 180 units, the difference between the 1000 units of the crude ore and the 820 accounted for in the dressed mineral.

As a rule the loss increases with the degree to which the ore is concentrated; and with some ores the value of the ore lost becomes, by enriching the mineral, greater than the increased market value of the ore. The only way to arrive at an exact conclusion as to the point at which concentration should be arrested is by actual assay of the crude ore, the various products, and of the steriles; while if silver is present as in argentiferous lead, a careful watch must be kept on the slimes in which the greatest loss of the precious metal usually occurs.

The following general rules * will be of use in the formation of an opinion as to the conditions under which the loss will in all probability be small:

If the ore is fairly hard, and breaks into smaller pieces without much dust of fracture.

If the ore is in itself of considerable density, and consists mostly of large grains easily detachable from a gangue of much lighter specific weight.

If the enriching operation is chiefly confined to hand-picking, and if only a small proportion of the stuff sent to the dressing mill is subject to treatment with water.

On the other hand, the loss of ore and cost of dressing will be considerable.

If the constituents of the ore and veinstone are composed of very small grains uniformly aggregated together.

If the ore and gangue are nearly alike in density.

If the ore is so friable as to disintegrate into powder by the absorption and mechanical action of water.

If the ore is sparingly associated or intermixed with veinstone, or if the veinstone is hard and the ore soft, or if both are subjected to a severe pounding or grinding action.

* "British Mining," by R. Hunt. London: Crosby Lockwood & Son.

If the ore in itself bears a high percentage of metal—as in the case of carbonate of copper, 57 per cent.—and simply stains the veinstone.

If a soft ore, thinly distributed or intermixed with hard veinstone, is pounded so as to shatter instead of detaching the orey particles.

In general terms ores containing native metal, or the sulphides may be said to be capable of concentration, while the carbonates and the oxides are almost always undesirable for concentration.

The physical character of the ore has much to do with it. Broadly, ores which are coarsely crystallised in separate crystals and not blended together make the most desirable concentrating ores. The eye is no guide; nothing but a practical test will determine whether or not an ore can be economically concentrated.

The loss occasioned in treating gold or silver ores by concentration may be found by the use of the following rule, as well as the percentage of metal saved.

Number of tons into one.—To find this, divide the weight of the original ore treated by the weight of the concentrates obtained.

Percentage saved.—This is found by dividing the assay of the concentrates by the degree of concentration, multiply this by 100 and divide by the assay of the original ore, as, for example, in the case of a silver ore.

Concentration . . 6 to 1.
Assay of concentrates in silver 40 oz.
Assay of original ore ,, ,, 8 oz.
$40 \div 6 = 6{\cdot}66 \times 100 = 666 \div 8 = 83{\cdot}2$ per cent. saved

CHAPTER XXVII.

ELECTRICITY AS A MOTIVE POWER FOR MINING MACHINERY.

Advantages of Electricity—Electrical Terms and Units—Efficiency of Electrical Transmission—Electrical Horse-power—Examples of Electric Transmission—Dynamo and Electromotor—Application of Electricity to Mining Machinery—The Pierrefitte Power Station—The Frongoch Power Station—Electric Mining Hoist—Electric Mining Pump—Electric Drilling Machine—Electric Traction.

Advantages of Electricity as Motive Power.—The recent advances in the science of electricity have opened up an immense field for its application as a motive power in mining and its associated industries.

The prohibitive cost of fuel for steam, and the want of a convenient supply of water, have been the cause of the failure of many a mining undertaking, but now the situation of a mine as regards its close proximity to water-power is no longer of such vital importance, seeing that the power of a river, even though many miles away, can be utilised by means of electricity for all the mill work as well as for the pumping and hauling at a mine which otherwise would be practically unworkable.

In illustration of the adaptability of electricity as a motive power for mining purposes, I have given a description on page 483 of a 1000-horse-power power station, erected by myself in 1899 on the direct current system at the Pierrefitte Mines in the Pyrenees ; and as an example of what is known as the alternating current system, I have inserted on page 496 an account of the power station erected at the Frongoch Mines, Cardiganshire, by my friend Mr. P. Nogara.

Let us first generally consider the nature of this new motive force and how these results may be obtained.

Practically, there is no definition of electricity, for up to this date, although great progress has been made in its application, no one has actually found out and determined what this subtle force is. All that can be done, therefore, is to point out some of the rules which regulate its use, and draw a parallel between it and one of the other sources of power with which we are more intimately acquainted.

The other science which will best serve as a familiar illustration of

electricity is that of hydraulics, and the following arrangement is possibly the best for the purpose of explaining the connection and relation between the dynamo or generator of electricity and the electromotor or machine by means of which the electricity is reconverted into motive power.

Underneath the streets of London and some other large cities are the high-pressure hydraulic mains, and through these pass the water which has been accumulated under enormous pressure, and which is used for the purpose of driving various motors and working hydraulic lifts in the city. The pumping station represents the dynamo or generating electric station; the hydraulic mains, the conducting wires; the water, the electric current; and the lifts or water-engines, the electromotor. It is evident that the power given out by the water-motors bears some relation to that employed to accumulate it under pressure, and depends upon the quantity and pressure supplied, which again is modified by the length and diameter of the conveying pipes, as well as by the resistance offered by the pipes to the flow of water.

An electric installation is subject to almost equivalent conditions. The power given out by the motor is a certain percentage of that absorbed by the dynamo, and this is subject to modification by the electric pressure or electromotive force (measured in "volts" instead of pounds per square inch), by the quantity of electricity (measured in ampères instead of gallons), and the resistance offered by the length, size, and quality of the connecting wires (measured in ohms), which represent the friction of the water in the pipes.

The "volt," or unit of electric pressure, is sometimes spoken of as electromotive force, or E.M.F., and is that amount of pressure which is sufficient to cause a current of 1 ampère to flow through a wire whose resistance is 1 ohm. The volt, therefore, is the difference of potential between any two points whether between the wires of the same system, between one wire and the ground, or between the wires of one system and those of another. In the case of a battery it is the difference of potential between the two poles. An ordinary Daniell's cell newly made up has an E.M.F. of 1·072 volt; a Leclanchè cell, as used for electric bells and household use, of $1\frac{1}{2}$ volt; and a bichromate cell, familiar from its bottle-shaped form, has an E.M.F. of nearly 2 volts. Recently some experiments were made at the Crystal Palace with currents having a pressure or E.M.F. or 130,000 volts. The "ohm" is the unit of resistance, and is that offered by a column of mercury 1 square mm. in section and 106 cm. long. A copper wire, 1000 ft. long and $\frac{1}{100}$th in diameter will, if the metal be nearly pure, offer a resistance of 1·0068 ohms at a temperature of 60° Fahr., while a wire of German silver only 36 in. long and $\frac{1}{200}$th diameter will offer a resistance of 1·12 ohm.

The term "ampère" expresses the unit of current, being the amount which a pressure of one volt can force through a resistance of one ohm,

while "coulomb" is the expression of quantity or flow of one ampère in one second. The ampère is obtained by the formula:

$$\frac{\text{Volts}}{\text{Ohms}} \text{ or } \frac{E}{R} = \text{Ampères.}$$

The table which follows (as in Mr. Power's "Miners' Pocket Book")* gives the various electrical units, their symbols, derivation, and value:

ELECTRICAL UNITS (MUNRO AND JAMIESON).

Unit.	Symbol.	Name.	Derivation.	Value.	
				C. G. S.	Equivalent.
E. M. F.	E	Volt	Ampère × Ohm	10^8	0·926 standard Daniell cell.
Resistance	R	Ohm	Volt ÷ Ampère	10^9	106 cm. mercury 1 sq. mm. section at 0° Cent.
Current	C	Ampère	Volt ÷ Ohm	10^{-1}	0·0000105 gramme of hydrogen liberated per second.
Quantity	Q	Coulomb	Ampère per second	10^{-1}	
Capacity	K	Farad	Coulomb ÷ Volt	10^{-9}	
,,	K	Microfarad	1 millionth Farad	10^{-15}	2·5 knots of D.U.S. cable.
Power	P	Watt	Volt × Ampère	10^7	0·0013405 or $\frac{1}{746}$ HP.
Work	W	Joule	Volt × Coulomb	10^7	0·7373 ft.-lbs.
Heat	W	Joule	Amp.² × Sec. & Ohm	10^7	0·238 caloric.

C. G. S. system is made up of the fundamental units: centimetre (for length), the gramme (for mass), and the second (for time) E.M.F. electromotive force.

The practical question, however, with which mining-men are especially interested is that of horse-power, and how to arrive at the mechanical effect which may result from the use of electricity. The unit of electric power is termed the "watt," and is the rate of doing work either usefully, as in electric light and the conversion of electricity into mechanical motion, or wastefully in heating the connecting wires and the dynamo and motor. The "watt" is the product of volts × ampères, and each "watt" is equivalent to 44·2359 ft.-lb., or 1-746th of an electrical horse-power. To arrive at the theoretical horse-power which may be expected from any known current of electricity, it is necessary to know the current in ampères, and the pressure or E.M.F. in volts, both of which may be obtained by means of instruments called ammeters and voltmeters. By multiplying together the readings obtained from these instruments and dividing the product by 746, we have at once the equivalent force of the current in horse-power. Thus $\frac{C \times E}{746} =$ horse-power. For instance, if a dynamo or set of batteries is giving off a current of 112 volts and 20 ampères as read by the meters, then the horse-power is $112 \times 20 \div 746 = 3$ horse-power.

* "Pocket Book for Miners and Metallurgists," by F. Danvers Power. London: Crosby Lockwood & Son.

If the number of watts only is given, then the horse-power is $\frac{\text{watts}}{746}$ = horse-power. In making electrical calculations as to the useful effect which will probably be obtained it is, of course, necessary to make ample allowance for losses from various causes, and these may amount to about 40 per cent. of the original power, made up as in the following case:

A mine is so situated that it cannot be worked on account of the cost of the fuel and its transport, nor is water-power available on the spot. A river flows about a mile away, and from this 100 horse-power can be obtained by means of a turbine or waterwheel. It is proposed to utilise this power for the working of the mine, and the following will be the approximate effective results obtained: Indicated horse-power at turbine, 100.

Less 10 per cent. loss in gear	90				
,, ,, dynamo . . .	9	81			
,, ,, connecting wires . .		8·1	72·9		
,, ,, electromotor . .			7·2	65·7	
,, ,, gear of motor . .				5·7	
				IHP. delivered at mine =	60
Therefore the efficiency of the system will be . . .				60	per cent.
and the losses of the system will be				40	,,

This result will compare very favourably with those obtainable by any other system, such as the cable and compressed air, while the erection of a mile or more of telegraph line is simplicity itself as compared with the cost and expense of putting up a travelling cable or laying pipes for compressed air. My own experiences as will presently be described, gave an efficiency of 56 per cent., and where distances are short and great care has been taken with the installation, it may rise as high as 60 per cent.; but for ordinary mining practice, it would be safer to reckon on 50 per cent. as the average efficiency.

A strong well-insulated cable can be carried over the roughest ground on stout poles, well stayed, and provided with lightning-conductors, with about 35 poles or spans per mile, the cost of the cables being £60 per mile of cable.

Again, to take another instance, we have a source of water-power capable of delivering 50 horse-power to the pulley of the generating dynamo, at a distance of $2\frac{1}{2}$ miles from a mill or mine, where we have 10 stamps requiring $2\frac{1}{2}$ horse-power each, and have selected a safe working E.M.F. and current, which will entail a loss not exceeding 10 per cent. in the cables.

The electrical efficiency of such a system would be about 64 per cent., or 32 horse-power given at the pulley of the motor. In addition

sufficient power could be spared to run 5 or 6 arc lamps, which would effectively light an area of 4800 ft.; or 12 stamps of $2\frac{1}{2}$ horse-power could be driven instead of the 10.

The loss in the connecting wires of an electric installation depends upon the material and size of the wires adopted, and also upon the perfection of the insulation of the line. Copper conductors are almost exclusively used, and as the resistance they offer depends upon their diameter, it pays best to have them of large section and pure material. The line of wire is always double, and the present methods of insulation are sufficiently perfect to prevent any appreciable loss from this cause.

The following table will give the horse-power when the number of watts is known:

Watts (C × E) HP. = 746 Watts.

Watts.	HP.	Watts.	HP.	Watts.	HP.	Watts.	HP.
		17,158	= 23	36,554	= 49	55,950	= 75
93·25	= $\frac{1}{8}$	17,904	,, 24	37,300	,, 50	56,696	,, 76
186·5	,, $\frac{1}{4}$	18,650	,, 25	38,046	,, 51	57,442	,, 77
373	,, $\frac{1}{2}$	19,396	,, 26	38,792	,, 52	58,188	,, 78
746	,, 1	20,142	,, 27	39,538	,, 53	58,934	,, 79
1,492	,, 2	20,888	,, 28	40,284	,, 54	59,680	,, 80
2,238	,, 3	21,634	,, 29	41,030	,, 55	60,426	,, 81
2,964	,, 4	22,380	,, 30	41,776	,, 56	61,172	,, 82
3,730	,, 5	23,126	,, 31	42,522	,, 57	61,918	,, 83
4,476	,, 6	23,872	,, 32	43,268	,, 58	62,664	,, 84
5,222	,, 7	24,618	,, 33	44,014	,, 59	63,410	,, 85
5,968	,, 8	25,364	,, 34	44,760	,, 60	64,156	,, 86
6,714	,, 9	26,110	,, 35	45,506	,, 61	64,902	,, 87
7,460	,, 10	26,856	,, 36	46,252	,, 62	65,648	,, 88
8,206	,, 11	27,602	,, 37	46,998	,, 63	66,394	,, 89
8,952	,, 12	28,348	,, 38	47,744	,, 64	67,140	,, 90
9,698	,, 13	29,094	,, 39	48,490	,, 65	67,886	,, 91
10,444	,, 14	29,840	,, 40	49,236	,, 66	68,632	,, 92
11,190	,, 15	30,589	,, 41	49,982	,, 67	69,378	,, 93
11,936	,, 16	31,332	,, 42	50,728	,, 68	70,124	,, 94
12,682	,, 17	32,078	,, 43	51,474	,, 69	70,870	,, 95
13,428	,, 18	32,824	,, 44	52,220	,, 70	71,616	,, 96
14,174	,, 19	33,570	,, 45	52,966	,, 71	72,362	,, 97
14,920	,, 20	34,316	,, 46	53,712	,, 72	73,108	,, 98
15,666	,, 21	35,062	,, 47	54,451	,, 73	73,854	,, 99
16,412	,, 22	35,808	,, 48	55,204	,, 74	74,600	,, 100

The distance which separates the motor from the generator has, of course, the effect of increasing the resistance offered to the passage of the current; but by employing copper conductors of adequate size this loss by resistance may be kept within reasonable limits, even when the distance is abnormally large, greater than will ever be required in mining.

For short distances, say under 3 miles, the direct current system will be found more convenient, and works at a comparatively low voltage; but for greater distances then the alternating high-voltage current system will be preferable, as with it much smaller conducting cables are required.

Mining presents a fair field for the employment of this new motive force, and already it has been employed for pumping, winding, underground hauling, coal cutting, and rock drilling; and, doubtless, as the number of appliances increase, so also will many mines be brought into a paying condition which, hitherto, because of their situation, they have never arrived at.

The question of the erection of an electric plant is not one which should present any difficulty to the well-trained mining man. The original motive power, when steam is not used, is either a turbine or a waterwheel, and with either of these appliances all engineers are familiar. The generating dynamo, or dynamos, according to the size of the installation, are connected with the turbine by means of suitable belting, or by direct coupling, as shown in fig. 317 (p. 488), the great point

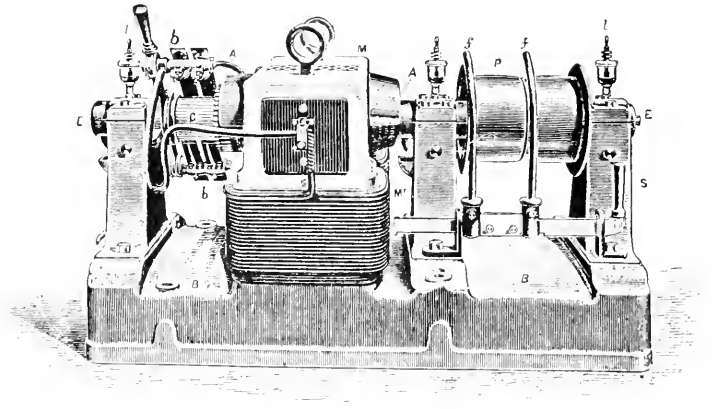


Fig. 311.—Dynamo.

being to drive the electric plant at a fixed and constant speed in order that the strength of the current may not vary.

As some of my readers may not be familiar with the construction of their machines, I will give a short description of a usual type; and as most dynamos will work equally well as motors, the same description will apply to both machines.

The dynamo is a machine for converting mechanical force into electric energy, and when used as a motor it reconverts the electric energy into mechanical force with some amount of loss, though small, as described on page 480. The machine itself consists of a cast iron bed-plate (B), fig. 311, on which there are three standards with bearings for supporting the shaft (E E). Upon the shaft is keyed an armature (A) consisting of a series of coils of copper wire, the ends of which are connected with the plates of the commutator (C). The armature is caused to revolve by means of the driving pulley (P) at a high rate of speed between the

poles of a powerful electro-magnet (M), the result being that a current of electricity is generated in the coils of the armature, passes thence to the commutator (*c*), and is collected by means of the brushes (*b*) from which it is conducted to the terminals of the machine, and thence to the lamps or motor. A fuller description of a dynamo will be found in Chapter XXVIII.

This particular type of machine is furnished with a third bearing, in order to better accommodate a loose pulley as well as the ordinary fast pulley. It is also fitted with a belt striking gear or band fork under the control of the lever (S), which enables the attendant to put the armature into motion or stop it without reference to the engine.

The outward form of the dynamo varies considerably according to the different makers, the type of armature and winding employed. The market price of copper also effects the price of electric machinery, and it is hardly necessary to add that the care and trouble spent upon the construction of a good machine, are well worth the extra cost charged by well-known makers.

If the terminals of a dynamo in motion be connected with those of a dynamo at rest, the current from the active machine will traverse the circuit of the idle one and cause the armature to revolve, converting it into an electromotor; and so we have the whole system of the electrical transmission of power exemplified, the efficiency of which is explained on page 480.

It will be seen that as regards erection the machine presents no difficulty; it is simply bolted down to a firm foundation and driven at a definite rate of speed by a well-governed motor, whether steam, water, gas, or oil, and at this speed certain known results can be absolutely relied upon.

The problem which is presented to the mine manager or engineer from day to day, is how to convert the water-power, probably running to waste near his mines, into electricity, and having converted it, how to reconvert it into power, and use it for the multitude of purposes presented by mining operations above and below ground. As my own experience may be valuable to others, I will describe how I solved the problem at the Pierrefitte Mines, in the French Pyrenees, quoting largely from a paper which I read before the Institute of Mining and Metallurgy in 1901, and which is published in the Proceedings for that year.

The Pierrefitte Electric Power Station.—The concentrating mill at the Pierrefitte Mines is situated on the side of the narrow valley, running up into the mountains from Pierrefitte to Cauterets and beyond to the Spanish frontier. Up to recently the driving power for the mill machinery was obtained from a series of waterwheels placed one below the other, and fed by the water of a very variable brook, a tributary

of the main torrent. This power was supplemented or replaced as occasion required by a steam-engine which at times drove the whole mill by itself, or took up part of the work in conjunction with the water-wheels. Such a system was most unsatisfactory and was liable to frequent breakdowns, in addition to which the yearly cost of coal was over £1000. Acting on my advice, the company decided to erect an electric power station on their own property close to the main river where there is always a minimum supply of 2200 litres per second (= 484 gallons per second), and to convey the power from thence to a large 100-horse-power air compressor up at the mines, and to the concentrating plant, in order to replace the old water and steam power.

The two essential points first to be determined were the minimum quantity of water in the river and the height of the fall available.

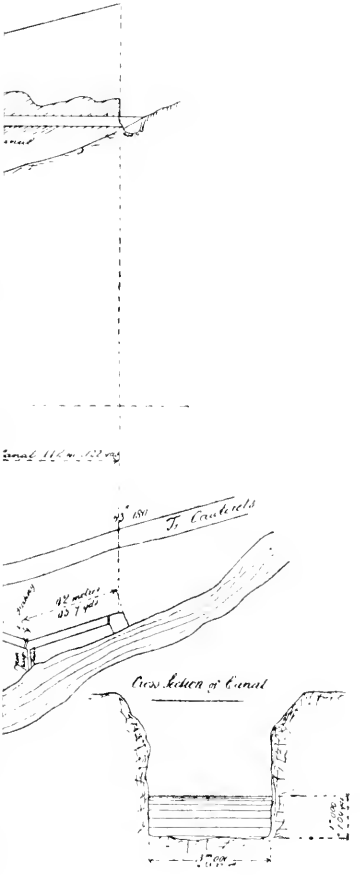
The river takes its source high up among the glaciers of the Pyrenees, and derives its summer supply mostly from the melting of the snow and ice, formed during the winter, so that, provided there has been a heavy snow fall in the preceding winter, a drought in summer does not affect the quantity of water, as the heat simply drives further back the advanced line of the glaciers, and so keeps up the supply.

About 2 miles higher up the valley than the Pierrefitte Mines, a 3000-horse-power electric station had already been erected, and is at work supplying power to the Pierrefitte-Cauterets Electric Railway, the engineer of which kindly placed at my disposal the results of their tests, as to the minimum quantity of water ever to be expected in the river; and this quantity both as gauged by them and previously by the government, was found to be 2200 litres per second, or equal to 29,000 gallons per minute, though all our calculations are based upon 2000 litres per second = 440 gallons.

In order to avoid any difficulty in the future from other proprietors desiring to use the available fall and so requiring a share of the water, it was decided to place the intake canal, the pipe line, and the power station entirely upon the company's property, and at a point where the position of the electric tramway and the steep slopes of the mountain on the opposite side of the valley prevented the possibility of any other works being erected between the intake and the outflow of the water.

Proper authority from the Government had also to be obtained before the water could be diverted from the river, and this was only given after long inquiries and public notices, though under the circumstances a provisional order was given for the commencement of the works while the formalities were being complied with.

The spot chosen for the intake, as shown in fig. 312, 313 (Plate XXII), which is a plan and section of the pipe line, was at a point where the canal could be naturally sheltered from the rush of boulders and timber down the torrent in flood-time, by means of a huge out-cropping mass of rock,



ıd Pipe Line.

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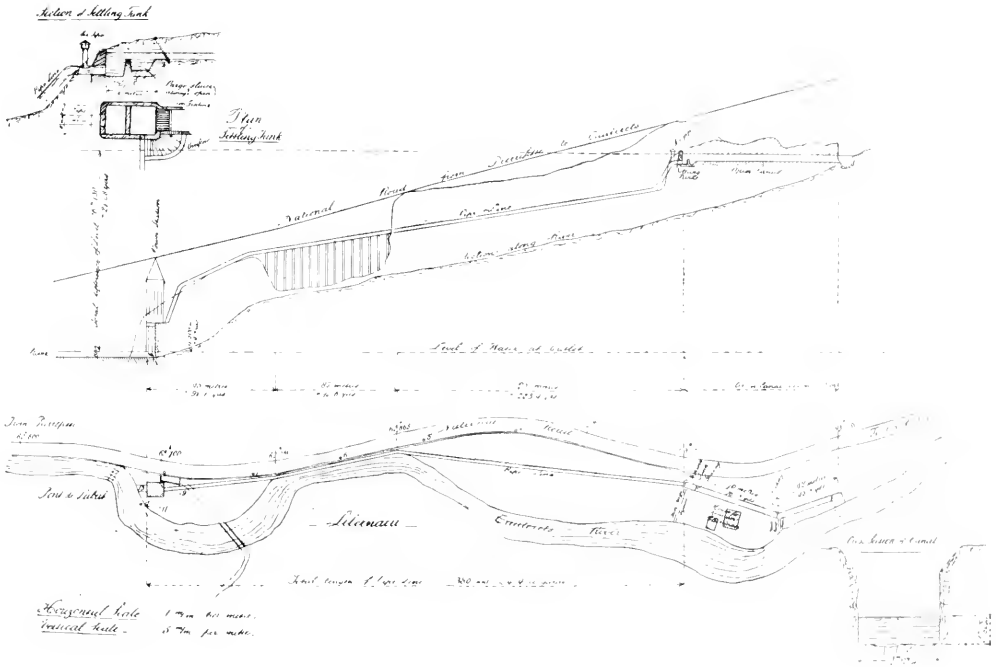

Figs. 312, 313.—Pierrefitte Electric Power Station: Section of Canal and Pipe Line.

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a few yards below which a natural shelf across the river bed allowed for the easy construction of a weir, if one should prove to be necessary which has not yet been the case.

This position is shown in Plate XXII., from which, also, it will be seen that immediately below the intake the river widens out, so that during a flood the water would be spread over a large area and would not be liable to submerge the canal. The total difference of level available from the intake to the outlet of the suction pipes below the turbine is 26,130 metres 85·7 ft., or allowing for the fall of the intake canal and friction of 24·5 metres = 80·3 ft. This would give an effective power of 417 horse-power, at a turbine consuming 1700 litres per second, and the power station was accordingly designed to accommodate two turbines, each of 420 horse-power coupled direct on to two generating dynamos of the same force, so that one set could always be kept in reserve, or if required both used together, for as a matter of fact the river so rarely falls to less than 4000 litres per second, that such an event is looked upon as a phenomenon.

In Plate XXII. will be found a section of the intake canal and line of piping. In cross section the canal is 3 metres = 9 ft. 8 in. wide, and the depth of the water is 1 metre = 3·2 ft. At the entrance near the sluice gates, the width is increased to 3·5 metres to allow for the contraction occasioned by the framework of the sluices. These are composed of two sheet steel doors, lifted by means of the ordinary windlass gear, which, together with the wall protecting the intake and supporting the sluices, are placed above any danger of floods.

The first portion of the canal for 42 metres = 137·7 ft. immediately behind the sluices, is cut in rock and ends at a flushing sluice placed at its side, which is designed to be kept always partly open, so that any gravel or heavy matter carried along from the river can constantly be drained out before it proceeds into the next section of the canal. At this point, at the entrance to the arched portion of the canal, the first iron bar grating is placed. The next section of the canal for a length of 70 metres = 229·60 ft. was also designed to be in open cut, but, as the ground was found to consist of loose boulders, it was decided afterwards to arch it in. The construction of this canal is shown in fig. 314 (Plate XXIII.). The earth was afterwards filled in on the top of the arch and the natural surface restored.

The speed of the water flowing in the canal was calculated to be 0·570 metres = 1·8 ft. per second, and in order to give this the total fall in its whole length of 123 yds. is 0·130 metres = $5\frac{1}{2}$ in. Experiments made after completion show these ends to have been obtained.

The arched portion of the intake canal terminates at the intake chamber, shown in plan and section in Plate XXII. Immediately in front of this on one side of the canal is an overflow weir for returning any

excess of water direct to the river. This is followed by an inclined iron grating to prevent the further progress of any floating matter, at which point also the canal widens out so as to increase the area to 10 metres = 10·9 yds. of sections, and reduce the speed of the water to 0·175 metres = 7 in. per second, in order to allow any sand to deposit in the first part of the intake chamber as shown in the section, and which is provided with a scouring sluice at the bottom. The purified water overflows into the actual intake chamber at the head of the pipe line, and the level of the water will always be 1·800 metres = 5·9 ft. above the top of the pipes so as to prevent the formation of eddies. The actual diameter of the pipes is 1·200 metres = 3·9 ft., but at the end they are bell mouthed and also covered with a coarse grating.

Pipe Line.—Although a diameter of 1·100 metres would have been theoretically sufficient to carry the quantity of water required, we decided to increase it to 1·200 metres in order to keep the velocity of the water down to between 1·500 metres and 2·000 metres per second = 6·5 ft., and also to decrease the loss of head in friction. The length of the pipe line is 382 metres = 416 yds., and the loss of head due from all sources is as follows :

In the open canal	0·130	metres
In the pipe line	1·030	,,
In the sluices and grating	0·470	,,
	1·630	,, = 5·34 ft.

so that the total available fall of 26·130 metres is thus reduced to a working head of 24·500 metres = 80·3 ft.

The slight increase in the diameter of the pipes increased the cost by 9 per cent, but the sectional area was thereby increased 18 per cent.—a great advantage for so small a cost.

Thickness of Pipes.—The strains which pipes of this nature have to stand are due to internal pressure, bending, expansion, sudden shocks, and possibly, also, a crushing strain by the creation of a vacuum. The thickness of the pipes to withstand a pressure due to a head of 80 ft. can of course easily be got at, but seeing that the sudden shocks which might arise from the quick closing of the valves and the tardy action of the safety appliances cannot be ascertained with any degree of accuracy, we decided to err on the side of safety, and basing ourselves on the known results obtained at other installations of a similar character in France, commenced with a thickness of 4 mm. and increased it gradually up to 8 mm., and for the lower half of the pipes used double riveted joints. The pipes themselves are in mild steel, each 3 metres long with flanged joints, and are bolted together. The joints are made with tarred cord.

Safety Appliances.—In order to prevent the possible formation of

Fig. 314.—Pierrefitte Electric Power Station : Construction of Intake Canal.

[*To face page* 486.

a vacuum in the pipes and their consequent collapse, a blast piece is fixed at the upper end close to the intake chamber, shown in fig. 312, which is simply a small chimney rising above the water-level, and which would permit the entrance of air if the gratings became choked.

After the pipes were laid, with the exception of the middle one, the expansion as between midnight and midday with the pipes empty was found to be 30 mm. = $1\frac{1}{4}$ in., and a double diaphragm expansion joint of the form shown in fig. 315 was put in at this point. Seeing, however, that the temperature of the river water is practically the same all the year round, it is probable that the expansion with the tubes full will never reach the amount provided for. The tubes are supported partly on the ground and partly on pillars, of which there is one for each

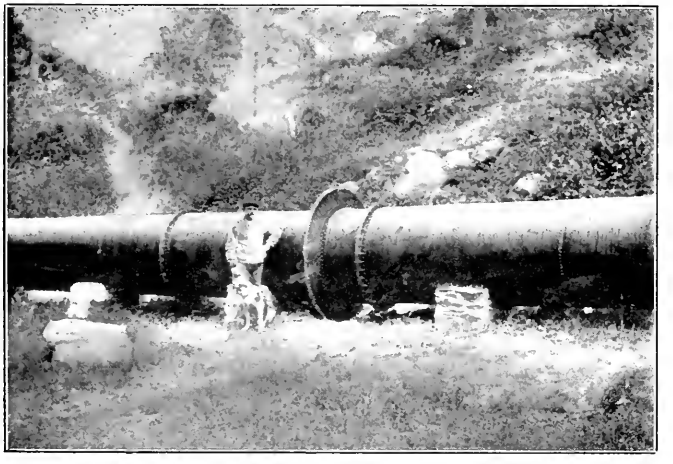

Fig. 315.—Expansion Joint on Pipe Line.

length of tube. A piece of boiler plate is put on top of the pillar to allow the tube to slip for expansion, and the pillars are built up against the side of the tube after it is placed in position. No difficulty was experienced while laying the tubes. They were unloaded on the highway, immediately above their respective positions, and slung over to their places. The joints were made with tar cord, and after being screwed up were also caulked from the inside. Two layers of tar were applied both inside and out.

The question as to what form of safety-valve should be used was long discussed, but was finally decided in favour of an upright chimney placed on the pipe line close to the power station. This chimney has a diameter of 16 in., and the top of it is a little above the level of the water at the intake. The level of the water in the chimney which is

shown in fig. 315 is continually varying, and in case of a sudden stoppage of the turbines, the water, instead of bursting the pipes, simply overflows from the top of the chimney. This often occurs as the strain in the dynamo varies. Such a simple appliance can only be used on comparatively low heads, but it is as effective as simple.

Instead of taking the pipes underneath the floor of the power station

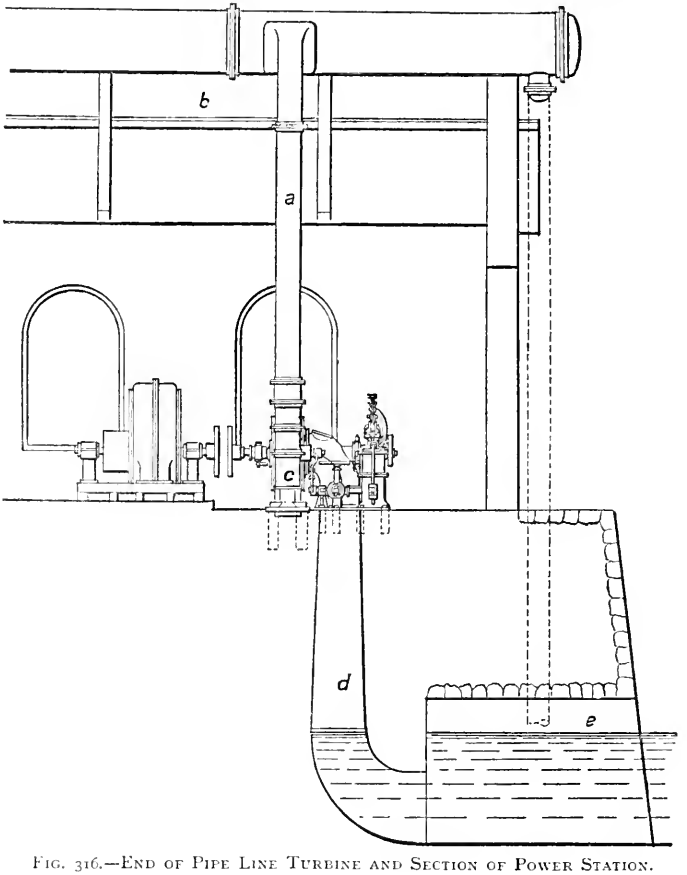

FIG. 316.—END OF PIPE LINE TURBINE AND SECTION OF POWER STATION.

and then up to the turbines, we decided to take them along the ridge of the roof, and then straight down through the turbines and suction pipes to the river.

The appearance of the pipes on the roof, as seen in fig. 316 and again in fig. 317 (Plate XXIV.), and of the T-piece at the end, from which the branch pipes descend to the turbines, is not artistic perhaps, but it has the merit of being extremely simple and efficaceous.

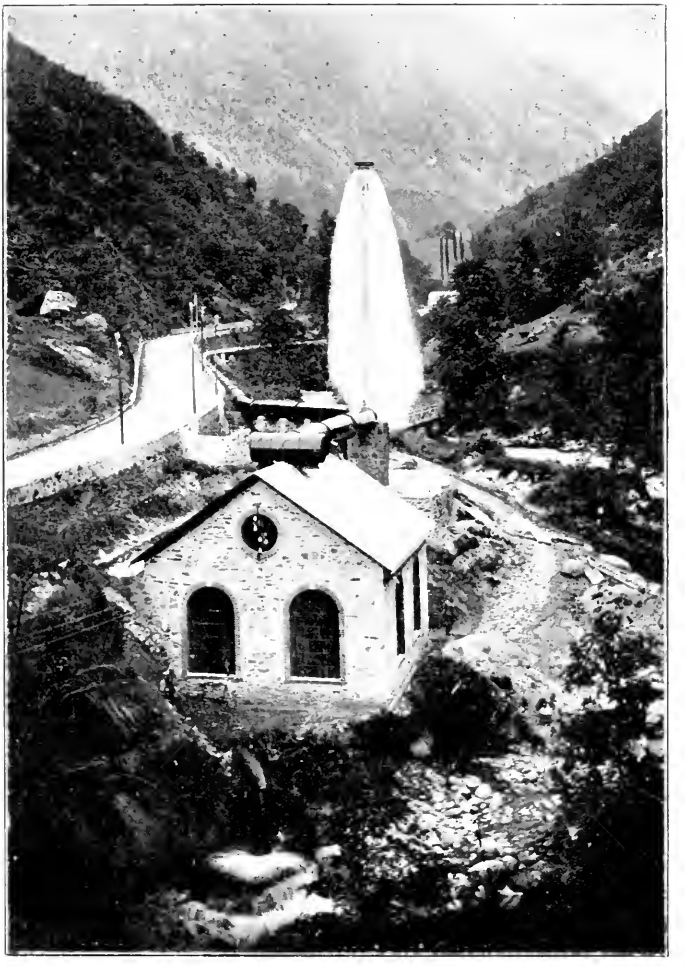

Fig. 317.—Pierrefitte Electric Power Station: Safety-valve in Operation.

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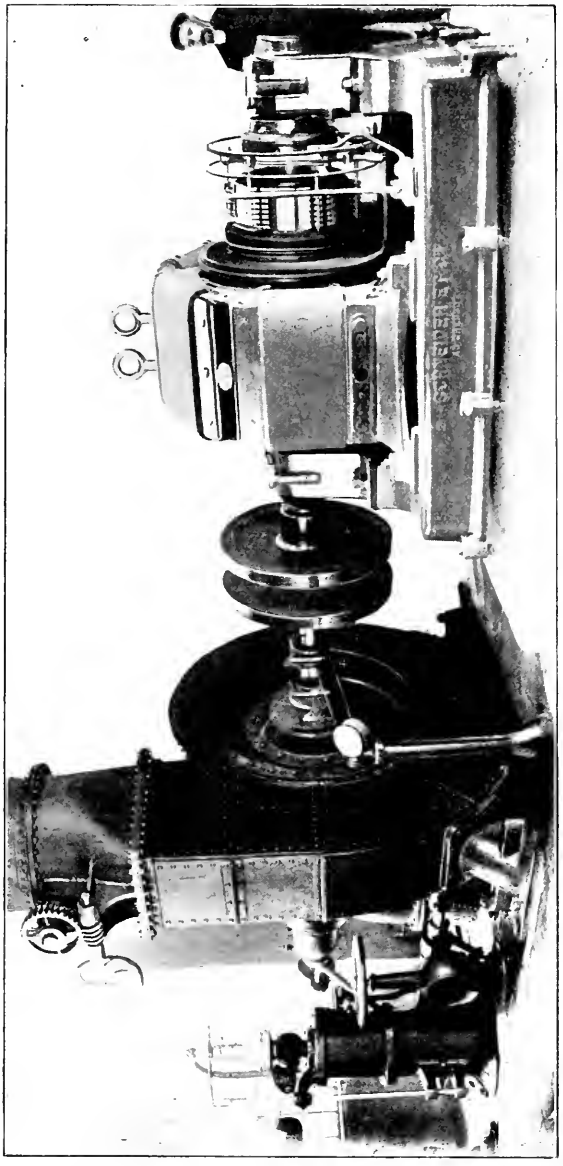


FIG. 318.—INTERIOR OF ELECTRIC POWER STATION.

Power Station.—The level of the floor of the power station is at 5 metres = 16·4 ft. above the level of the river, so that it is beyond all danger of floods ; and for this 5 metres the water acts by suction below the axle of the turbines from which the outflow pipes, passing under the floor

of the station terminate in a square water chamber by means of which their ends are always kept 2 ft. under water, while the waste water flows over the edges of the chamber into the river. This is shown in fig. 316.

The internal dimensions of the power station are 11 × 10 metres The roof is supported on steel principals which also carry part of the weight of the pipes, the remainder being distributed on the vertical pipes, down to the turbines which act as pillars, and the pinion at the end of the building.

The side wall next to the hill also acts as a retaining wall to the road above, and has two strong buttresses, though as the excavation was for the most part in solid rock the push against the masonry is but slight.

The interior of the power station is shown in fig. 318. The turbine is by Escher Wyss & Co., of Zurich; and the direct current generating dynamo (fig. 319)—which, as well as all the other electric machinery, was made by Messrs. Schneider & Co., of Creusot—gives 400 ampères at 750 volts, and runs at a speed of 425 revolutions per minute.

The turbine is fitted with a delicate speed governor, and all the connecting wires are brought up to a marble switch-board, on which are fixed the ammeter, voltmeter, cut-outs, and switches. Two men are kept night and day in the power station, in order to comply with the government regulations, but beyond oiling and cleaning the machines they have little to do.

Line Wire.—The distribution of the electric force is divided into unequal portions—namely, for the mine and the mill. At the Pierrefitte Mine the air compressor, which is one capable of driving 10 drills with a pair of cylinders 14 in. × 24 in., made by Messrs. R. Schram & Co., of London, described on page 173, absorbs 80 horse-power although 100 have been allotted to it; while at the Garoulere Mine a smaller air compressor requiring 20 horse-power is to be erected. The total length of this line of wire from the power station to Garoulere is about $2\frac{1}{2}$ miles. The mill actually absorbs 154 horse-power, but as a new and more power concentrating plant is shortly to be added, the wires erected are capable of supplying the balance of the power or 300 horse-power. The length of this line of wire from the power station to the mill is about one mile. A double line is in both cases erected. The four cables start from the switch-board, and run in one span to the side of the electric tramway. Special permission had to be obtained in order to cross under this, and the bare wires were here changed for insulated lead covered cables threaded through a 3-in. diameter gas-pipe, and this was enclosed in an earthenware drain-pipe buried underneath the tramway. On the opposite side the insulated cables were again taken to the top of a post and connected with the bare wire cables which here separate, the one pair going straight up the precipice to the compressor house, 2000 ft. above, and the other and thicker pair along the side of the valley to the concentrating mill.

Considerable difficulty was experienced in stretching these wires, owing to the rocky and precipitous nature of the hillside. The poles for the line to the compressor were first of all taken up to the mine, in the aerial

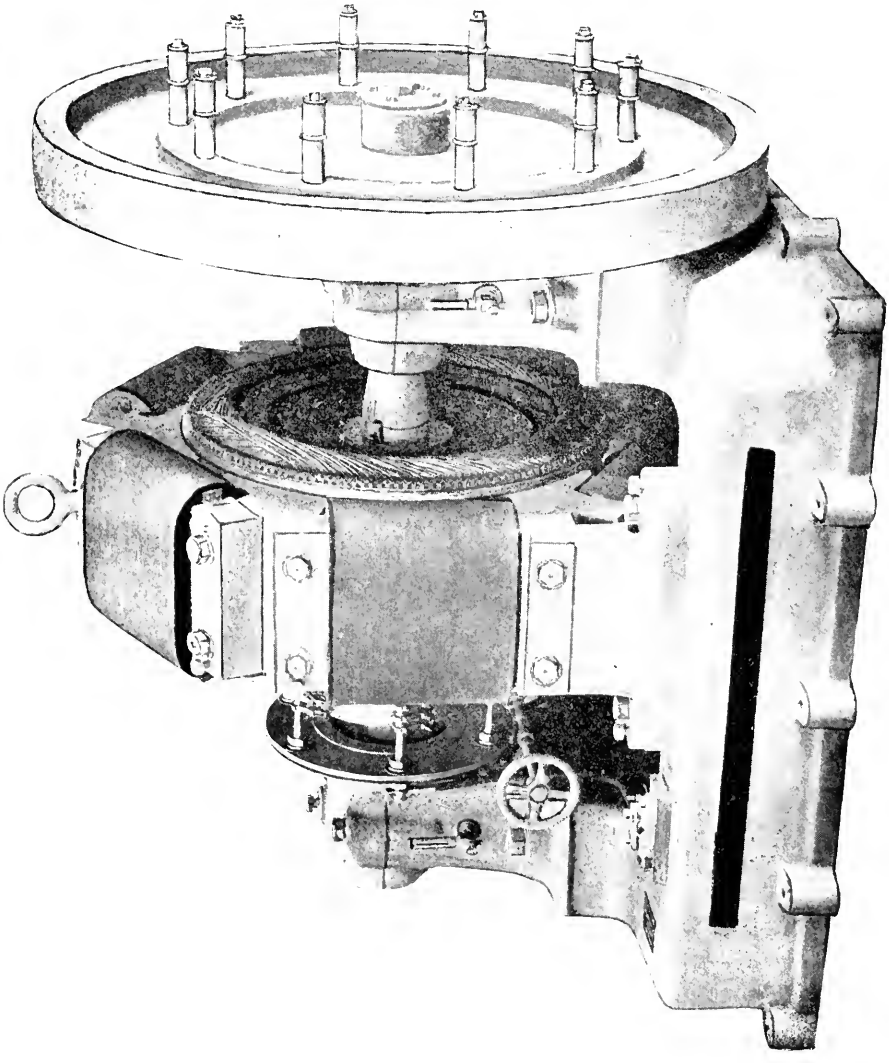


FIG. 319.—THE GENERATING DYNAMO.

tram, and then lowered down the side of the cliff to their places. The spans were very uneven and varied from 50 to 100 yds. according to the nature of the ground.

The voltage of 750 was chosen in order to be under the same

conditions as the electric tramway, so that, if need be, we could assist them with our current or they with theirs in case of breakdown at either of the stations. Before the generating dynamo had arrived we hired current from the tramway company, and worked five of our motors with it, the price paid being 40 francs for 47 kilowatts (or about 63 horse-

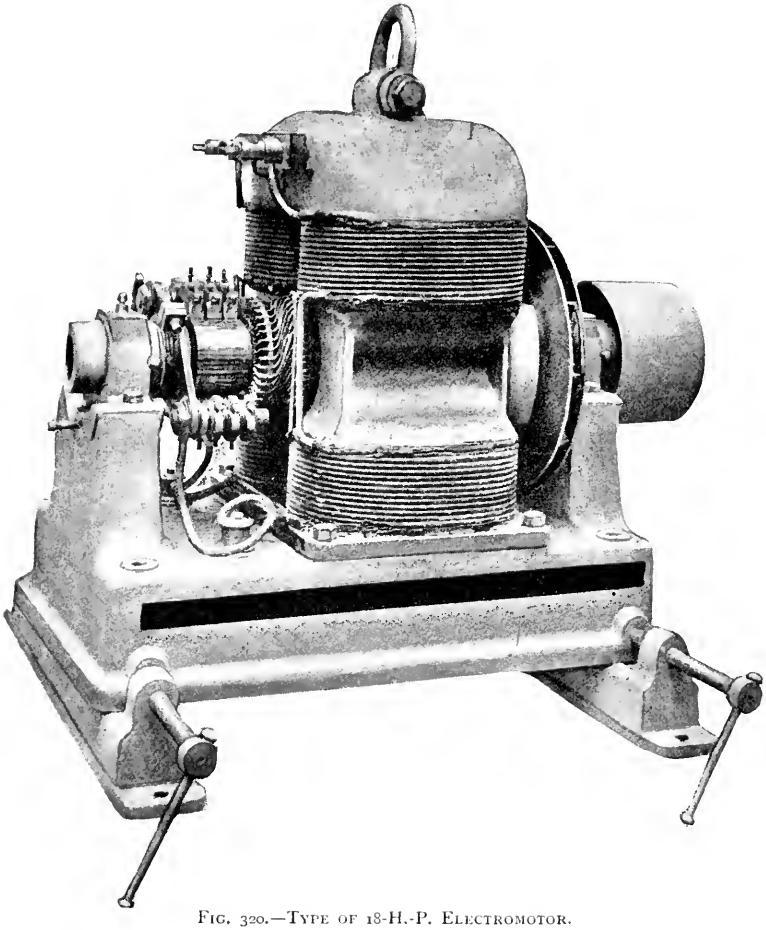


FIG. 320.—TYPE OF 18-H.-P. ELECTROMOTOR.

power) per 16 hours. The tramway naturally use their rails from the return circuit, so that a temporary connection was easily made between our line wires and their overhead wire and the rails, the arrangement working most successfully for nearly two months until our own power station was complete.

Generating Dynamo.—The type of this machine, known as H

by the Creusot Company, is shown in fig. 319 from which it will be seen that it has six poles. When running at full power it requires 420 horse-power, and it is coupled direct on to the axle of the turbine as shown in fig. 318, which is a general view of the interior of the machine-house. The method of coupling is shown in fig. 319, where a number of turned steel pins are shown projecting from the coupler. There is a similar arrangement on the coupler on the turbine shaft, and these pins are connected together, either by strong indiarubber rings or by means of a leather strap woven between them, thus taking up all jar.

Electromotors.—The concentrating plant consists of three separate and distinct portions: The stone-breaking and picking-floors the No. 1 mill, and the No. 2 or recrushing mill, and in each mill there are three distinct lines of shafting, the one driving the roller crushers, and the other two the jiggers and Lührig vanners respectively.

The electromotor driving the stone-breakers (fig. 320) was the first one erected. This, as well as all the electric work, was constructed by Messrs. Schneider & Co., of Creusot.

The foundations are very simple consisting of, first, a bed of concrete upon which was built a masonry pillar, up to the level of the floor of the motor-room, the total depth of the masonry being 4 ft. The motor itself weighs about $1\frac{1}{2}$ tons, and is carried on sliding bars for tightening the belt and adjusting. Under each bar, and bolted to it, are three large-sized insulators of the ordinary bell pattern, but inverted.

The motor with bars and insulators was placed upon the masonry block and adjusted, and then the block was built around the insulators up to their rims and covered with a finishing layer of cement, with which also the concrete and masonry were made. As the speed of the motors is high, 950 revolutions per minute, a short line of transmission shaft was in each case put in to reduce the speed to 80 revolutions, the speed of the jigger and other shafts. All the six 18-horse-power motors were erected in the same fashion, and were enclosed in small rooms in order to keep them free from the dust and dirt of the mill. Each motor is provided with a starting rheostat, similar to that shown in fig. 320, and a cut-out, and in every case they started clean away as soon as the connections were complete and have run, much to the astonishment of the natives, without any hitch or trouble ever since.

The following is a list of the motors actually in work:

	Fig.	Volts.	Amps.	Speed.	H.-P.
1 Compressor motor . .	319	680-700	115-120	450	100
1 Crusher	319	680-710	33	850	30
5 Motors for jiggers and vanners . . .	318	680-710	22	950	18
1 Machine shop motor .	318	700	8·4	1300	10

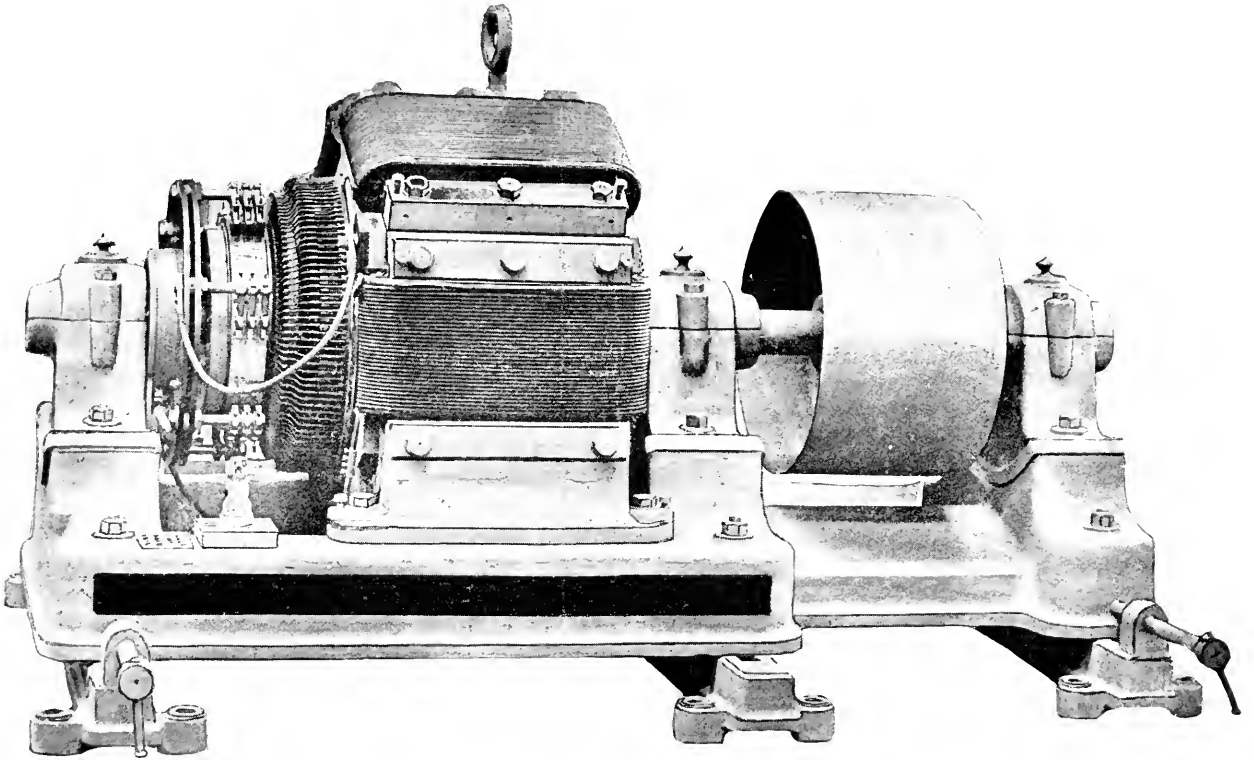


FIG. 321.—100-H.-P. ELECTROMOTOR USED FOR DRIVING A SCHRAM COMPRESSOR.

Mine Motor.—The 30-horse-power motor driving the roller crushers and the 100-horse-power motor driving the Schram air compressor, are shown in fig. 321. It will be noticed that there are four pole motors. They differ in size, being of different power, but their appearance is the same. Their dimensions are given in the preceding list. A strange accident happened to this latter motor during my last visit to the mine in December, 1900. The motor man reported that when restarting after dinner a flash of fire occurred all around the collector, whereupon he shut off the current. There was nothing visibly wrong with the machine, but the same event happened when I caused it to be restarted. Thereupon it was more closely examined, and finally the mashed remains of a rat were found inside the armature, where he had apparently taken

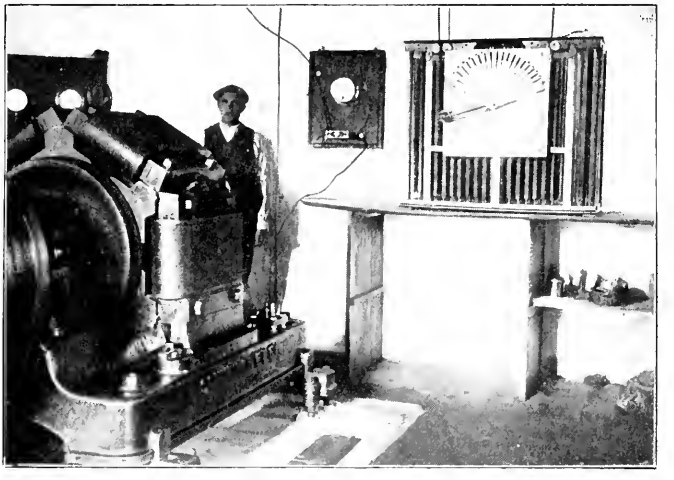


FIG. 322.—STARTING RHEOSTAT AND 100-H.-P. MOTOR.

refuge during the dinner hour. His blood caused a short circuiting across some of the collecting wires, and the machine stood idle a week for repairs.

The total cost of the works complete was £8000, and the work was carried out by contract to my satisfaction. The total efficiency of the system worked out at 56 per cent. of the theoretical power in the water feeding the turbine.

When the distance between the power station and the motors is comparatively short, the direct current can be used with advantage, but when it is considerable, then the advantage lies with the use of high tension alternating currents; the cable lines for which can be of small weight as compared with the low voltage direct current lines.

The Frongoch Electric Power Station.—I am indebted to my friend Mr. B. Nogara, an Italian engineer, for the following description of an alternating current high voltage plant, which he recently erected at the Frongoch Mines, Cardiganshire—the first example of its kind (I believe) to be erected in Wales. The mines are of old standing, and have been worked with varying success for lead and blende for many years. They have recently been taken in hand by a Belgian firm, who have replaced the old pumping and milling machinery formerly driven by water-power by a modern concentrating mill and electric winding and pumping gear.

In the immediate neighbourhood there are three large reservoirs capable of supplying water for about nine months in the year; it being customary in Wales to collect and store in such reservoirs the rainfall which in the mountainous districts of that country reaches about 1·80 metres per annum.

A new water-course was constructed about 5000 metres long, which collects on its way the water coming from the discharge valves of the above reservoirs, carrying it to a fourth reservoir of the capacity of about 40,000 cubic metres.

This new reservoir has been placed at a suitable point for creating a fall of 126 metres, the water being conveyed to the bottom of the valley by riveted steel pipes 450 metres long and 0·50 metres in diameter. At the bottom of the fall an *electric generating station* has been erected which supplies the mine with 400 horse-power all the year round. The electric generating station includes:

1 Tubular boiler, Babcock & Wilcox patent, giving steam to the engine at 160 lb. pressure.

1 High-speed vertical engine, Willans & Robinson patent (Rugby, England). (The boiler and the steam engine have been fixed alongside the water-power plant for the dry months of the year and as reserve plant.)

1 Pelton wheel with automatic governor; supplied by Escher Wyss & Company, of Zurich, Switzerland.

1 Threephase alternator of the Allgemeine Electricitate Gesellschaft, of Berlin.

In addition to these main parts of the generating station there are: the dynamo for the excitation of the alternator as well as for the lighting of the engine-room and boiler-room, switch-board with all resistances, measuring instruments, fuses, cut-off, etc., and 12 ton overhead-travelling crane for the contingency of repairs.

Two elastic shifting couplings enable either the steam engine or the Pelton wheel to drive the threephase generator, all machinery being run at the same speed of 350 revolutions.

The electric current is generated at 2300 volts, and carried to the

mine by means of bare copper wires for a total distance of about 2000 metres from end to end.

At 1200 metres distance is situated the dressing mill, fitted for treating 15 tons of crude ore per hour.

The dressing mill is equipped with 2 high tension electromotors of 50 horse-power each, but capable of 75 horse-power each if required.

One electromotor drives the trommels, the jiggers, the slime tables, and the pumps; the other drives the crushing machinery.

From the main line at this point is taken the current for the electric light, and for this purpose a 10 kilowatts transformer is fitted up and three series of arc lamps are derived, each series being of six lamps, but only fifteen lamps are burning now, three having been found unnecessary.

At 650 metres distance from the dressing mill is the main winding shed, and here two electromotors of 75 horse-power each are derived from the main line. One electromotor, a high tension one, is situated in the mine at the 160 metres level, where the current is conveyed by means of highly insulated cable. This motor is fixed on the cast iron basement of a three Ram pump, capable of delivering to surface 25 litres of water per second or 1500 per minute.

The electromotor is connected by an elastic coupling to the main pinion shaft and runs at 537 revolutions.

A small transformer situated in the pump-room gives the current for the incandescent lamps of the said room and of the main 120 metres level.

The second electromotor of 75 horse-power, a low tension one, is situated on the surface and supplies the power for the double drum winding machine, to which it is connected by means of an elastic coupling.

The motor is so constructed as to give 125 horse-power for the starting of the windlass.

Between this low tension motor and the high tension line a 60 kilowatts transformer is naturally introduced, reducing the voltage from 2200 volts to 220 volts.

The main feature of this electric winding plant is the resistance for regulating the work of the motor and the commutator for reversing the current, and consequently the rotation of the motor.

The reversing of the current is obtained by the engine-man handling a single lever. This reversing lever is so connected with the brake as to prevent in any way the starting of the motor when the brake is acting. The arrangement is a very simple and original one and very useful, as it has achieved its object of simplifying to the utmost the manœuvres to be done, and of preventing the accidents caused by false manœuvres which in this case are entirely obviated.

From the transformer fixed in the winding shed are derived the lamps for lighting the winding-room, the tipping platform of the shaft, the sorting-shed, and the top end of the endless chain.

On the way from the dressing mill to the main winding-shed a small transformer supplies a low tension current for the lighting of the offices of the mine.

At 175 metres distance from the main winding-shed another 30, horse-power high tension motor has been fixed. This motor is connected by means of an elastic coupling to the pinion shaft of a small single drum windlass. The accompanying diagram (fig. 324, Plate XXV.) shows the electric plant with all details as to power, number of revolutions, voltage, instruments, lighting arresters, connections, size of the wires, etc., and gives a good idea of an electric installation for all purposes of mining work.

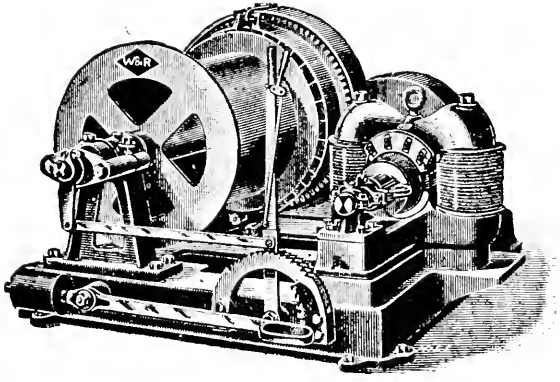


Fig. 323.—Electric Mining Hoist.

With this plant, at an outlay of about £10,000 sterling, the Belgian Company have secured 400 horse-power for the mine all the year round at a comparatively low price per unit.

The uses to which electromotors can be put in connection with mines are innumerable. I have already described several instances in connection with the Pierrefitte mill, and, referring my readers to page 172, they will find a description of its use in driving an air compressor. There is indeed hardly a large mine of importance in South Africa or the United States where electric power is not now used for mill work, pumping, winding, haulage, or tramway work. In addition to what I have already written I will illustrate its use in one or two additional ways.

Electric Mining Hoist.—The illustration (fig. 323) shows the arrangement for attaching an electromotor to a hoisting drum to be used for winding purposes exactly as steam is so employed. The motor, which runs at a speed of about 1000 revolutions per minute, is connected by means of spur gearing with the drum. The speed of the motor is controlled by an electric switch at one side, by means of which it can be varied by a single movement of the switch handle. Turning the handle to one notch will make the motor run slowly; through two notches, faster; and full number of notches, at full speed; while turning

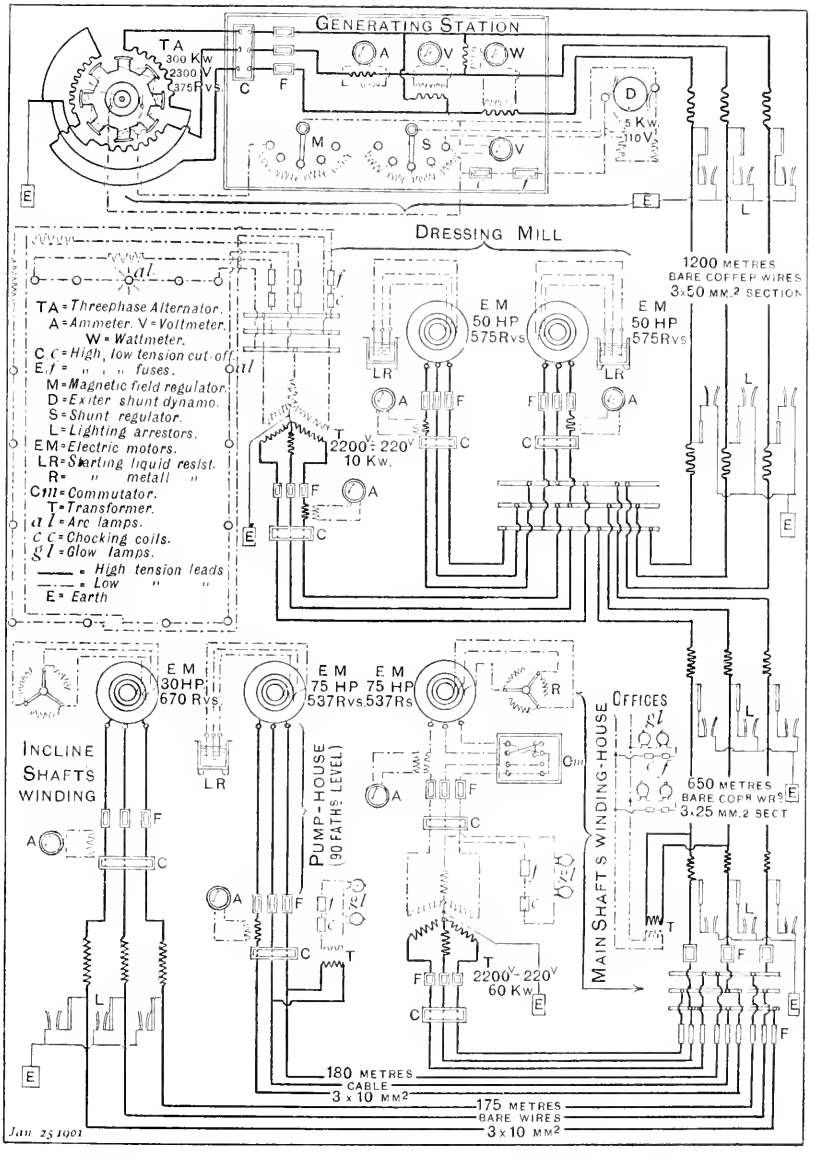


Fig. 324.—Diagram of Electrical Plant at the Frongoch Mine.

[To face page 400.

the handle in the opposite direction will give similar rates of speed with opposite direction of rotation. In other words, the hoist is reversed. The gearing is all boxed in iron cases in order to protect it from dust and stray stones, while for use underground in fiery mines, the commutator can be made on the safety principle which avoids all danger of explosion from sparking.

The drum is provided with a strap brake worked by a foot lever, so that the whole machine is immediately under the control of its driver. The efficiency of the electromotor when working under its full load is claimed to be over 90 per cent.—that is, that more than nine-tenths of the energy which is delivered to it in the form of an electric current at the terminals of the motor are transformed to effective work at the armature pinion.

Electric Continuous Rope Hauling Machine.—From winding to hauling

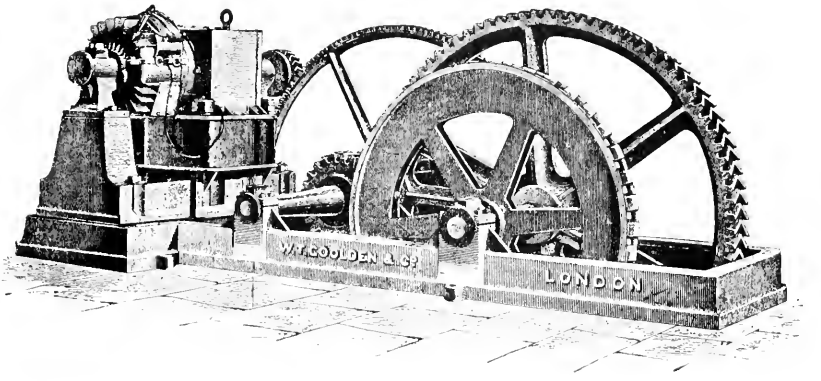


Fig. 325.—Electromotor Driving a Continuous Rope Hauling Plant.

is but a short step, and fig. 325 represents an underground hauling engine of the "Goolden" type, consisting of a strong cast iron bed-plate, carrying a dip pulley driven through two sets of gearing by means of a Goolden mining motor of the safety pattern.

The shafts are of Siemens-Martin steel, turned all over with feather keyways, and running in bearings lined with phosphor bronze liners with strong cast iron caps.

The gearing is of cast iron with double helical teeth, the wheels being turned and faced on the bosses, and have deep keyways slotted into them. The clip pulley is also of cast iron, turned and faced on the bosses, and securely keyed to the shaft with independent clips giving great grip without damage to the rope.

The engine is started and stopped by a switch of the "Goolden" non-sparking type, whereby absolutely no spark is produced on breaking

the circuit, the whole being enclosed in a strong gas-tight iron box, and when necessary means are provided for starting or stopping slowly.

In metalliferous mines there is of course no necessity for the safety gas protector. It is, however, extremely useful in keeping all dust and dirt from the armature of the motor, and for this reason alone is worth retaining.

For main and tail hauling the arrangement is somewhat similar to that used for hoisting, except that two drums are employed driving

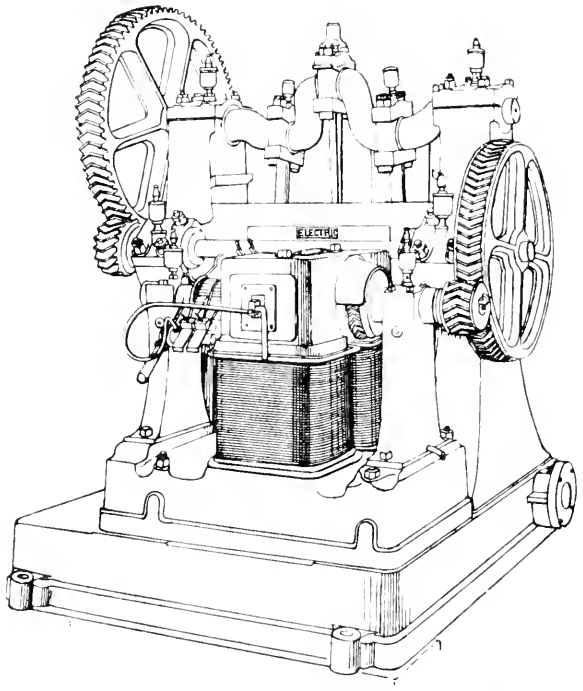


Fig. 326.—Electric Mining Pump, showing Electromotor.

through a clutch gear, by means of which either drum can be driven for drawing up either road, while the other is free for paying out cable.

The motors are connected by means of cables with the generating dynamo, situated at the mouth of the shaft or at the source of water-power.

Electric Mining Pumps.—All mining engineers are intimately acquainted with the use of pumps driven by steam or water, whether on the surface or underground. Some of them have employed compressed air for this purpose, and now a rival of these motive forces has come into the field in the shape of the electric current, which, because of the ease

with which it can be conducted to the scene of operation in difficult places by means of flexible cables, is likely to come into very general use for the purpose of underground drainage.

The electric mine pump, such as is illustrated in fig. 326, is now at work under heads of over 600 ft., and its efficiency, as ascertained by careful independent tests, amounts in horse-power of water delivered to 75 per cent. of the brake power of the engine. The price of the insulated double cable connecting the dynamo to the motor of the pump is about £10 per 100 yds. for the smaller sizes.

The pump shown in the drawing (fig. 327) is a three-throw ram pump driven through cast iron gearing by an electromotor, the whole machine being mounted on a cast iron bed of box pattern.

The pump cylinders are of cast iron fitted with phosphor bronze ram bushes, the rams being of cast iron or gun metal if specially ordered. The valves and seats are of brass of large size, and the shaft and countershafts are of steel, forged in one piece, running in bearings lined with adjustable phosphor bronze or gun metal bushes, fitted with syphon lubricators.

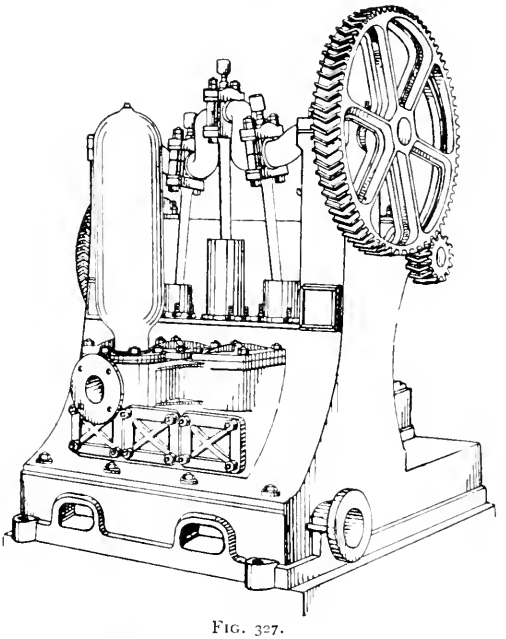


Fig. 327.
Electric Mining Pump, showing Three-Throw Pump

Electric Drilling Machinery.—An electromotor can be readily attached to the rotary drills used for boring in coal and soft shale, and will make a hole of from $\frac{1}{2}$-in. to $1\frac{3}{4}$-in. diameter at the rate of from 6 to 15 in. per minute to a depth not exceeding 3 ft. 6 in. For boring in the hard rock usually met with in metalliferous mining, no electric drill has yet been manufactured which will compete with the ordinary air-driven rock drills, which, in addition to boring a hole, at the same time largely assist in the ventilation of the workings. Its use in connection with a diamond rock drill is shown on page 208 (fig. 140).

If electricity cannot be applied direct to the drill it can, however, be used with advantage in driving the air compressor, and will practically annihilate the distance separating the compressor from the cheapest source

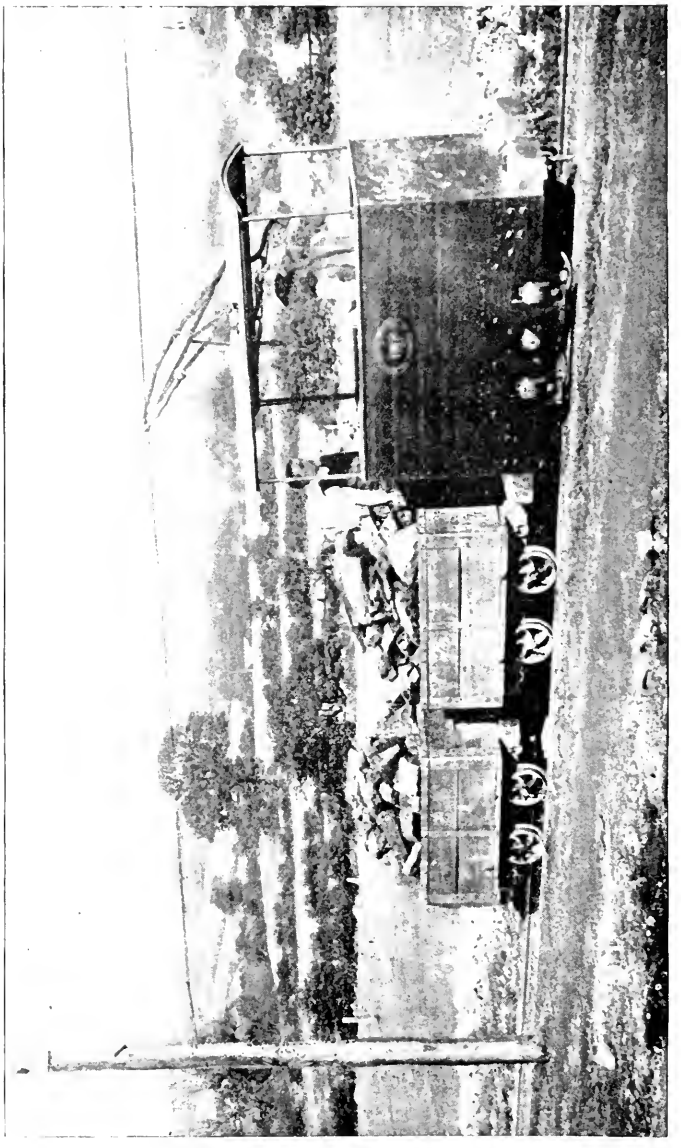


FIG. 328.—ELECTRIC LOCOMOTIVE FOR MINING PURPOSES.

of motive power—water. The difficulty and loss from leakage and friction, of conducting air in long lengths of piping from the compressor situated near a river to the mine, possibly a mile or more away, is overcome by placing the generating dynamo at the turbine and conducting

the current any reasonable number of miles by cable to the motor at the compressor. The same current can be used for lighting or other purposes, and the mine both above and below ground rendered independent of steam and costly fuel.

All that is required is that the high speed of the motor should be reduced by a train of gearing to the comparatively low speed of an air compressor or other machine, and this in the case of a compressor is effected in the manner shown in Plate III. (page 172), which shows the arrangement I adopted successfully at the Pierrefitte Mines. The belt tends to relieve the heavy strains on the motor at the first starting of the compressor.

Electric Traction.—Hitherto I have spoken of the use of electricity in its application as a motive power to stationary machines.

Soon after its introduction for this purpose, however, it became evident that it could be equally well used as a means of locomotion, and with its use in this connection the majority of my readers are now doubtless familiar; for since the first edition of this book was written, electric tramways have been introduced into almost all the towns and cities of the world. For underground purposes the general arrangement is practically the same, though of course on a smaller scale. In fig. 328 will be seen an illustration of a Thomson-Houston electric locomotive at work in a colliery.

The overhead cable is attached to insulators fixed in the roof or the timbers, and the current passing down the flexible pole, which makes a running contact with the wire, is controlled by the switches at the disposal of the driver and returns to the generating dynamo *viâ* the motors on the locomotive and through the wheels to the rails. In fiery collieries such an arrangement would be too dangerous on account of the sparks, but this does not apply in metalliferous mines, where electric traction is in common use both for underground and surface haulage.

CHAPTER XXVIII.

ELECTRIC LIGHTING AND ELECTRIC BLASTING.

Electric Lighting—Arc and Incandescent Systems—Dynamo for Lighting Purposes—Series Shunt and Compound Wound Machines—Erection of Dynamo—Conductor's Switch-board—Example of a Joint Arc and Incandescent System—Trial Run—Working Rules—The Arc Lamp—Incandescent Lamps—Electric Blasting.

Electric Lighting.—The use of electricity for lighting purposes is so well known that it need not be brought before mining men as a novelty. The point which concerns them more especially is how to erect the necessary machinery if they are called upon to do so. This has fallen to my lot on several occasions, and in giving an outline of the procedure, I avail myself to some extent of the printed instructions issued by the firm of Sautter, Harlé et C^ie^, of Paris, whose dynamos and lamps, both arc and incandescent, I have erected and run successfully over a long period.

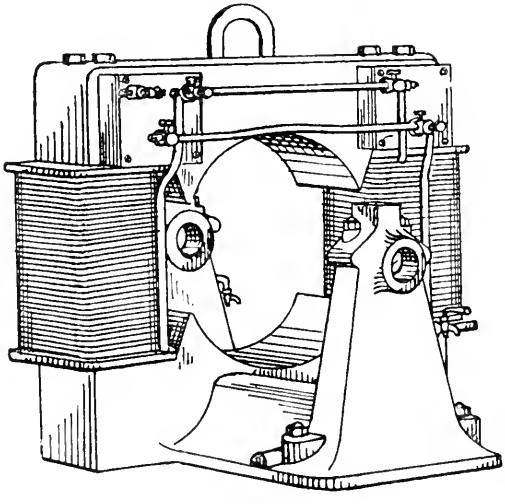


Fig. 329.—Framework of Electric Light Dynamo.

The two words "arc" and "incandescent" at once bring us face to face with two different systems of lighting, both of which have their merits, and both of which can be carried out from the same dynamo at the same time, provided that the dynamo is designed for that purpose.

Lighting by arc lamps is suitable for large, open spaces, by means of a few powerful lamps fixed at the head of tall poles. Incandescent lighting, on the contrary, is adapted to the illumination of the interior of mills, mines, and offices, by means of a large number of lamps of small

power, say each equal to 16 candles, which can be put wherever they are required, and, once the line of insulated conducting wires is established, give no further trouble.

In the chapters devoted to electricity as a motive power, I have already referred in general terms to the construction of a dynamo, and in figs. 329 to 334 will be seen the various parts of an unmounted machine which, when put together, for a complete dynamo, as shown in fig. 333.

In fig. 329 will be seen the framework of the machine made of soft cast iron, and with the field-magnet coils in place. By unscrewing the two set pins seen on each side of cap of the dynamo these coils can be removed; but in that case great care must be taken to remake the connections exactly as they were found.

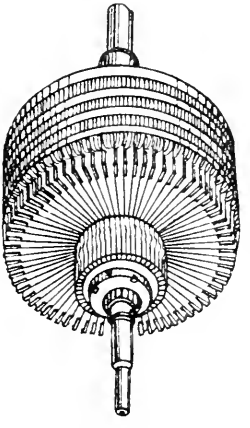


Fig. 330.—The Armature.

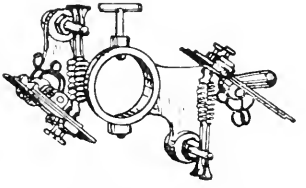


Fig. 331.—The Brushes and Brush-holder.

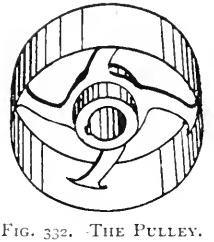


Fig. 332. The Pulley.

Fig. 330 is the armature, consisting of a large number of coils of insulated wire wound over a cylinder formed of soft iron wire. The ends of the coils are fastened to the radiating strips of copper, and these latter to the bars of the commutator, from which the current is collected by means of the brushes (fig. 331).

The brushes are fixed on a frame which can be turned to a certain extent in order to allow of their adjustment, which should lightly touch the commutator on a diametrical line slightly off the horizontal, as will be seen in the general view (fig. 333.) After the machine has been running continuously for some time, it becomes warm, and its electrical balance being disturbed it may be necessary to advance the brushes, which is done by unscrewing the set pin, the handle of which is seen, and turning the brush holder until a point is arrived at, where the sparking between the

brushes and the commutator is reduced to a minimum. The frame is then fixed at this point by means of the set screw.

The armature revolves in the long bearings shown, and is driven by the pulley (fig. 332) keyed to its shaft. As the cap of the dynamo is removable, the whole machine can be readily unmounted for cleaning, and fitted together again with ease.

As the armature revolves between the poles of the field magnets, the small amount of residual magnetism of the iron excites a current of electricity in the coils of the armature, and this current, feeble at first, increases the magnetism of the poles, which in their turn excite an increased current, and so the machine after a very few revolutions attains its maximum. The power required to turn the armature increases likewise, and it is this mechanical power which is converted into electrical energy, and produces the current required either for lighting purposes or for reconversion after transmission to a great distance into mechanical force.

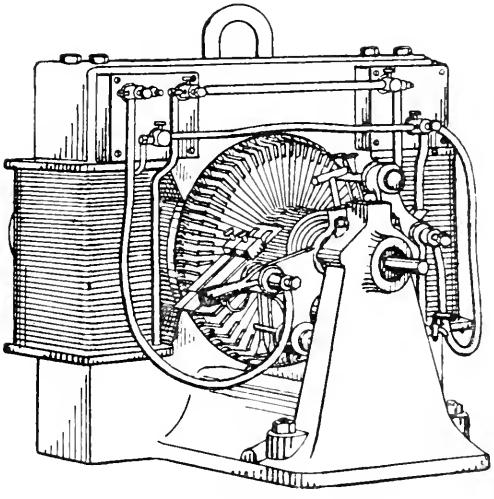


FIG. 333.—THE COMPLETE DYNAMO.

I have said that the slight current induced in the armature by the first few revolutions passes through the field magnets and increases their magnetic intensity.

In some dynamos the whole of the current is allowed to pass through the field magnets. These are called series wound, and are especially used for supplying the current to a large number of arc lamps arranged in series, by which is meant that the current passes through the whole of the lamps one after another.

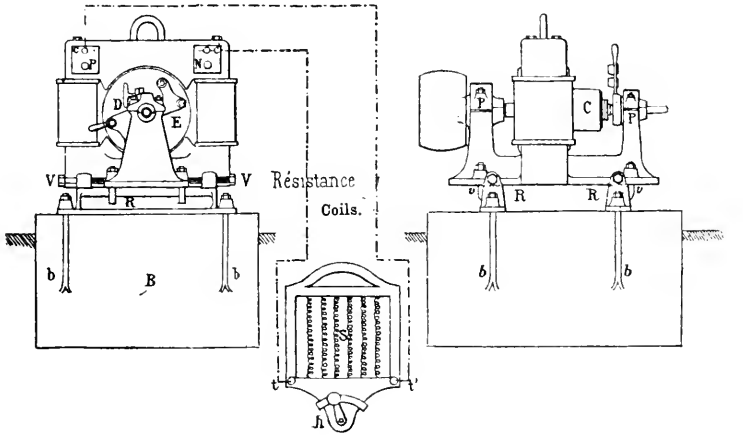
In other cases only a portion of the current is allowed to pass through the field magnets of the dynamo, and the machine is then said to be shunt wound, and is adapted for the purpose of charging accumulators, though it may be also used with certain modifications for arc or incandescent lighting.

Lastly, we have the compound dynamo, the field magnets of which are so arranged that through a portion of them the whole of the current passes, while the other portion is shunt wound. This class of dynamo is the one most generally useful, as it will supply both arc and incandescent

lamps at the same time, which is exactly what is required in mining, when we have to provide for lighting the open spaces surrounding the surface works, as well as the interior of the mill and the mine.

As the compound shunt wound dynamo can be used for arc or for incandescent lighting singly or for both at the same time, and as the instructions for the erection of this type of dynamo will serve generally for that of any other, we will now consider how a combined lighting plant may be installed.

It is absolutely essential that a dynamo should be driven at a fixed, unvarying speed, so that if it is proposed to connect it by belt to a line of shafting which drives other machinery, the speed of that shaft must be uniform, and should not vary more than 3 per cent. If this regularity



Figs. 334, 335.—Foundations for Dynamo (End and Side).

cannot be relied upon, then a special motor, either steam or water, must be supplied, and this motor must be provided with a sensitive governor. It may be connected direct to the shaft of the dynamo if the speed is high enough, or, as is more usual, by means of a belt. The belt must be just sufficiently tight as to avoid slipping, which would cause the lamps to flicker, and yet not so tight as to cause the bearings to heat.

The dynamo itself should be bolted down to a block of masonry, if possible; if not, it should be fixed on a rigid wooden framework, and in a room by itself, or railed off from other machinery and inquisitive onlookers, where it can be free from dust and damp and from metallic particles. It must be kept absolutely clean and free from oil and the dust caused by the wearing away of the brushes and the commutator.

In order to take up the slackness of the belt the dynamo it often mounted on rails as shown in fig. 334, at R, so that by adjusting the

screws (v v) the belt can be either tightened or slackened. B is the masonry foundation, *b b* the holding-down bolts, D the brush holder, and E the brushes. In fig. 332, the side view, *c* is the commutator, and P P the two bearings. The pulley is shown in its place.

It has already been explained that in the compound shunt wound dynamo the coils of the field magnets are wound partly with thick wire through which the whole current passes, and partly with fine wire through which a portion only is shunted from the terminals of the machine. Now this machine, if the speed is regular, will maintain a constant E.M.F. in volts, irrespective of the number of ampères of current which may be required from it by any variation in the outside circuit due to one or more lamps being turned on or off.

In order, however, to maintain a constant electromotive force, upon which the durability of the lamps depends, irrespective of any slight variations in speed, it is usual to place a series of resistance coils (S), fig. 334, in the shunt circuit between the terminals (t t'), of the dynamo, and by modifying this resistance, increase or diminish the amount of current sent through the shunt coils and so counterbalance any irregularities in the speed and maintain a fixed E.M.F., or difference of potential, between the main terminals (P N) of the dynamo.

The engine and dynamo having been fitted up, we must next consider the outside circuit and how to connect it with the dynamo in such a way that the arc or the incandescent lamps may be lit up at will either together or separately.

The conducting wires employed are of copper, insulated for interior work, but bare and supported by porcelain insulators on telegraph poles when used for outside work. The size of the wire depends on the strength of the current in ampères, and varies throughout the system according to the number of lamps in use, just as the diameter of a gas-pipe is varied according to the number of burners. The diameter of the wire is calculated on the basis of two ampères for each square millimetre of section of the wire.

Referring now to fig. 336 (Plate XXVI.), which is a sketch plan showing the general arrangement of a plant for lighting by arc and incandescent lamps, the two terminals (P N) of the dynamo are connected, the one to the main switch-board (B) the other to the fusible cut-out (E) to which all three return wires of the different circuits are brought and which, together with the switch-board and resistance coils (S) should be placed on the wall of the dynamo-room in a convenient spot. The fusible cut-out (E) as well as all the other cut-outs in the various circuits, consists of a short length of lead wire fixed between two terminals which fuses if the current exceeds a predetermined limit, and so saves the whole circuit and the lamps from destruction. One of these cut-outs is placed at each principal junction in the incandescent system, the diameter of

the lead wire being varied according to the amount of current it is designed to carry.

The series of resistance coils (S) for the shunt wires is shown in position, and their use has already been explained.

The pole (P) is connected to the positive bar (K) of the switch-board, and then branches off to the various circuits. For the incandescent circuit it is led first through a fusible safety cut-out (D D) and then to switch (I) by means of which it can be turned on or off, thus lighting or extinguishing the whole of the lamps at will. To each group of lamps, or to each lamp, if necessary, a smaller switch is connected, so that they are under absolute control. These switches, as well as the smaller fusible plugs and the way the lamps are connected, are clearly shown in the diagram.

The circuits of the arc lamps are somewhat more complicated. Each of these circuits—which may consist of two arc lamps, working in series as at L_2, with an E.M.F. of 120 volts, or of one arc in derivation, as L_1, with an E.M.F. of 70 volts—traverses a regulating resistance coil (R) as well as a fusible cut-out (D D) and a switch (C) for interrupting or completing the circuit.

When the switch handle is in the position (x y) the circuit is closed and the lamp will light up. When the handle is in the position (z w) the lamp will remain alight, but the current will also pass through the ampèremeter (A) the needle of which will then indicate the strength of the current in ampères. In the position (v w) the circuit will be interrupted and the lamps put out.

On each of the arc lamps will be found a label stating the number of ampères at which it should be worked. This exact number must be obtained by placing the handle in the position (z v) and then varying the resistance by means of the sliding knob (H), until the needle of the ampèremeter indicates the number desired. This adjustment once made, the handle can be put in the position (x y), and the lamp will continue to burn. It is advisable, however, to renew the test from time to time in case of any variation.

The first trial run of the installation must be conducted most carefully, and the dynamo should be allowed to run unloaded for a few hours. For this purpose the brushes are lifted from the commutator, and, after seeing that the machine is well oiled, a trial run should be made at the speed stated on the dynamo. During this trial the belt can be adjusted, the engine governor set to the proper speed, and various odds and ends seen to. Before lighting up, the following observations should be made:

1. That the brushes are firmly fixed and properly adjusted so that they may touch the commutator on opposite points of the same diameter, and that their holders are not in the way of the revolving armature.

2. That there is no connection between any part carrying the current and the framework of the dynamo.

3. That all the principal switches are open, so as not to allow any current to pass.

4. That all the bolts and screws are tightened up.

5. That the belt is well stretched and smooth, as any unevenness in its surface will cause the lights to flicker and shorten the life of the lamps.

6. That the oil cups are full of clean oil. The best lubricant is a mineral oil of a density of ·905.

Now raise the brushes and start the engine slowly; then, after a few moments, lower the brushes until they touch the commutator. If no part commences to get hot and if the voltmeter (v) indicates the proper number of volts decided upon for the installation, a portion of the incandescent system can be turned on and then increased at intervals of a few minutes until all the lamps are in circuit; and then, if all goes well, the arc lamp circuits can be added one at a time.

At each increase of the load in the dynamo it may be necessary to adjust the brushes by slightly turning round the brush holder until there are no sparks.

If, when the dynamo is at work, the proper number of volts cannot be obtained even by altering the resistance (s) it is probable that the speed is too low, and must accordingly be increased until the proper number of volts, as indicated by the voltmeter (v) is obtained. Great care must, however, be taken that this number be not exceeded by more than 5 volts, as otherwise the incandescent lamps will be rapidly destroyed.

In order to stop the machine the switches must first of all be turned off and the engine then stopped, but before the armature has quite ceased to revolve the brushes should be lifted.

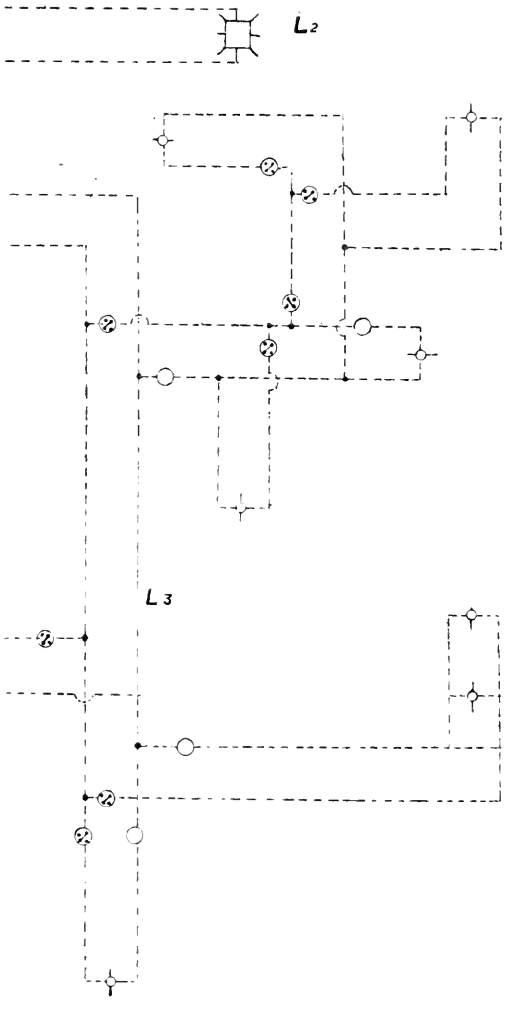
Great care should be taken not to bring any piece of iron near the machine when in motion. It is best even to use oil tins made of copper, as all iron tools are strongly attracted.

The contact surfaces of the switches, brushes, and commutators must always be kept quite clean.

No strangers or idlers should be allowed to tamper with the machine, or enter the dynamo-room, or interfere with the conducting wires, nor should any examination of a circuit be made until the current has been cut off from that portion of it.

There are many minor but important details which require careful attention during the erection and maintenance of an electric light installation, but enough has already been said to give, I believe, a general idea of the whole and the most striking features in connection with the dynamo and the circuit of conducting wires.

The Arc Lamp.—The area of ground to be illuminated and the nature of the work to be carried on must be considered in choosing



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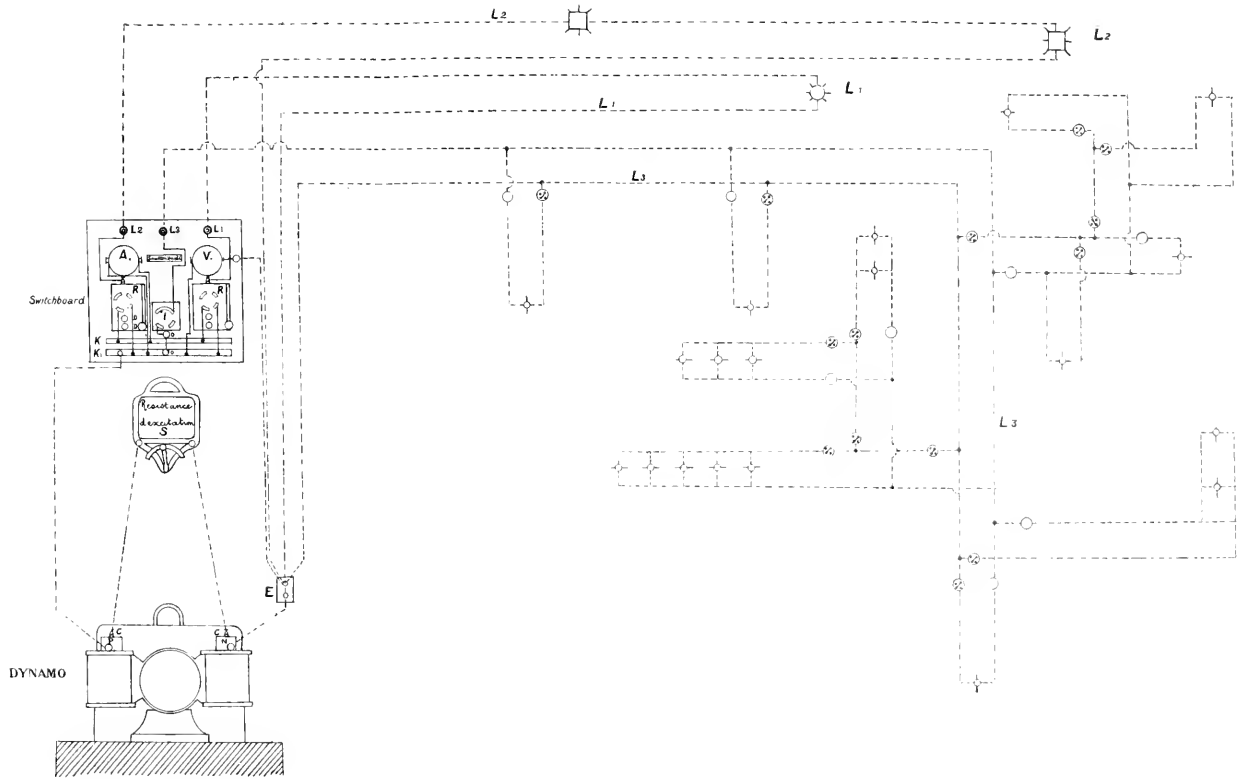

Fig. 336.—Diagram illustrating Arrangement of Electric Light Circuit.

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the candle-power of the lamps. In exceptional cases for large areas, where the lamp can be suspended at a height of say 100 ft. from the ground, an arc lamp requiring a current of 50 ampères and equal to a light of 19,000 candles would be chosen.

Generally speaking, however, a lamp giving 4500 to 5000 candle-power, requiring a current of 24 ampères, and hung at a height of 50 ft., would be found ample for illuminating an excavation equal in area to a circle of 8000 square yds.

For still smaller works out of doors, or in large workshops, a lamp of 1500 candle-power, requiring a current of 13 ampères, hung at a height of 30 ft., would be found convenient, especially in places where it would be desirable to use several lamps of small power instead of one of great intensity.

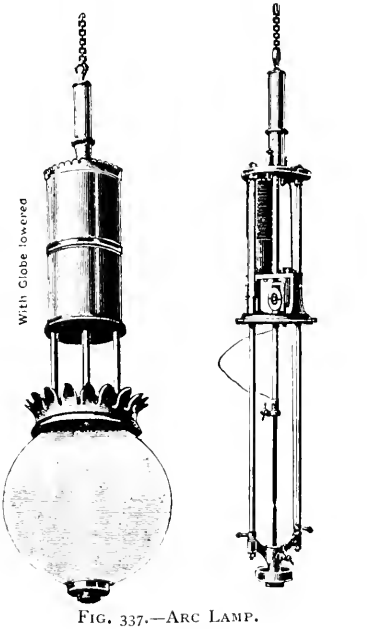


FIG. 337.—ARC LAMP.

The arc lamp, such as that illustrated in fig. 337; is more efficient than an incandescent lamp as regards the amount of light obtained from a given quantity of electricity; but both have their special applications. For outdoor use it must be protected by means of glass from the inclemency of the weather; but it should be remembered that all shades, even of clear glass, greatly reduce the illuminating power.

In the arc lamp the maximum is so arranged that the two carbons are kept at a certain distance apart, and over this distance the voltaic arc is formed which gives the light, the resistance thus offered to the passage of the current being overcome by its electromotive force.

The carbons employed in the lamps are consumed unequally, the upper one, which is connected to the positive pole of the dynamo, wearing away with twice the rapidity of the lower one. For this reason it is usual to make it of double the thickness of the other, so as to equalise the consumption. It will be noticed when in work, that a crater is formed in the extremity of the upper carbon while the lower one is always pointed.

The lamps are hung in such a manner that they can be easily lowered for cleaning, and the renewal of the carbons. Great care must be taken in fixing the new carbons to put them exactly in line, point to point. It is hardly, perhaps, necessary to add that these lamps are not lit by means of a match, though I once found a boxful of burnt match

ends at the foot of an electric light pole in a Welsh quarry, the explanation of which was that owing to a stoppage of the dynamo the lamp had gone out, and had been lowered by the night foreman, who ingeniously endeavoured to light it up again by the only means in his power.

Incandescent Lamps.—The pear-shaped glass globes within which is seen a thin horseshoe-shaped carbon filament, as in fig. 338, are now so well known as to require but little description. They are attached to small, round wooden supports, on which are the terminals under which the ends of the conducting wires are screwed. These supports also serve to hold a tin shade which reflects the light downwards. For household purposes they can be arranged in a great variety of ornamental and artistic ways with which, however, we have not at present to deal.

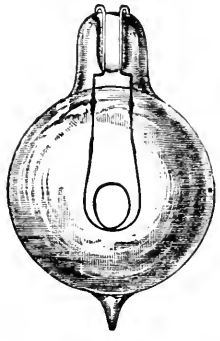


Fig. 338.
Incandescent Lamp.

The life of an incandescent lamp depends entirely upon the regularity of the current. Its maximum may be 2000 hours, but variations in the speed, stopping, or bad joints in the driving belts will cause rapid destruction of the thin filament. Perhaps for workshop purposes the average life of the 16 candle-power lamp generally employed, may be taken at from 800 to 1000 hours. Hence the necessity which has all along been insisted upon, of an absolute regularity of speed, which, indeed, can only be obtained by having a motor, whether steam engine or turbine, devoted solely to the driving of the dynamo.

Electric lighting is now being largely introduced for the purpose of lighting up the main roads underground, both in collieries and mines. In economy it will compare very favourably with any other illuminating power, while, if water-power is available for driving the dynamo, it is cheaper than any other form, and gives a far better light with no danger of explosion.

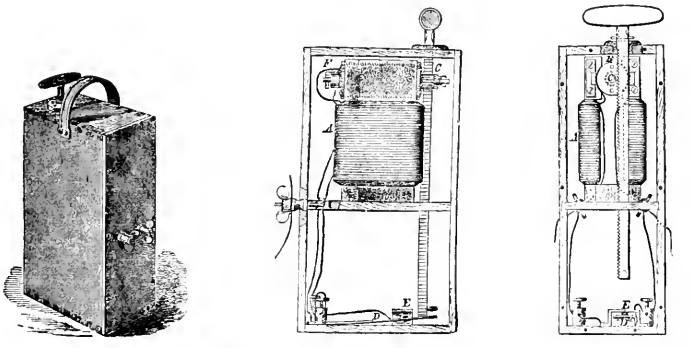
At the Pierrefitte Mines, the power installation of which I have already described, the voltage of 750 was too high for use direct. I therefore coupled the incandescent lamps in series of five, which brought the voltage down to the capacity of the lamps. For the same reason the arc lamps were coupled in series of two, but a resistance coil was also put into the circuit.

At another installation which I erected at a mine in Wales the power was only available during the day, so that a battery of accumulators was required. This was charged during the daytime and partly discharged at night. In this latter installation a small Pelton wheel was coupled direct on to the shaft of the generating dynamo, and as the pressure was constant the speed was also invariable. This is the

simplest form of installation and gives little trouble and requires but little attention, especially if accumulators are not required.

I have not referred to alternating current high tension dynamos, partly because my own experience with them is limited and also because with the exception of installation on a large scale, where the presence of a properly qualified electrical engineer would be required, the ordinary mining man will rarely have to do with them.

Electric Blasting.—The simultaneous discharge of a large number of holes is far more effective for the breaking down of rock, whether in tunnelling or quarrying, than is the result from the same number of holes fired separately. The best and safest way of attaining this is by the use of electricity, and the machine usually employed for generating the electric current is a portable arrangement of a small hand dynamo,



General View. Section, Side. Section, End.

FIGS. 339, 340, 341.—HAND DYNAMO FOR ELECTRIC BLASTING.

such as that shown in figs. 339–341, which may be wound in such a manner as to give high or low tension currents.

These machines can be made to fire up to a hundred holes at a time; but the usual type is for about 12 to 15 holes.

The armature (B) is caused to revolve between the poles of the magnet (A) by means of the rack and pinion (B) during the down stroke only of the handle. As soon as the lower end of the rack comes in touch with the contact breaker (E) the current is directed to the outside circuit of fuses and the explosion takes place. If by chance there is a miss-fire the holes can be examined at once, after disconnecting the machine, as it is impossible for a fuse to hang fire as with gunpowder. I have worked with these machines on a large scale, and after personally superintending the operation for a few days, during which time I trained a man to make up the fuses, connect the wires, make the joint, and

so on, I left the work solely in his charge, and although the number of holes often exceeded fifty in one blast, there was never any irregularity or trouble.

The fuse used with a low tension machine is shown in fig. 342, in which A is a shell of copper, having a slightly raised rim for the purpose of holding the sulphur stopping (F) in its place; the exterior wires (F) terminate in two pin points (D) forming a bridge, across which a connection is made by means of a fine platinum wire. On the current passing, this wire becomes red-hot and fires the explosive fulminate contained in the head of the shell, which has been inserted in the central hole of a dynamite cartridge, as usual with ordinary caps.

FIG. 342.
ELECTRIC FUSE.

The wires attached to the caps may be cut of any length to suit the depth of the holes and are generally left, the one slightly longer than the other, in order that the two joints may not be close to each other. The holes and fuses are joined in series, as shown in fig. 343, and great care should be taken that the joints between the wires should be properly made. For this purpose the insulating cover is removed for an inch or two, and the bare wire brightened with emery cloth. The ends thus cleaned can then be twisted together, thus connecting the line of holes. The starting wire of the first hole, and the terminal wire of the last one are then joined on to each of the connecting insulated wires, which in turn are fastened to the binding screws of the battery. All being now ready and the miners in safety, the handle is raised to its full height and pressed firmly down. When it touches the spring at the bottom the shots will be fired.

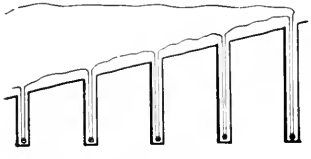


FIG. 343.
ARRANGEMENT OF WIRES FOR ELECTRIC BLASTING.

The points to be attended to are to make clean and perfect joints, and to so twist the wire at the joints that these do not come into contact with the rock, which might lead to the short circuiting of some of the holes. The firing cartridge may be placed at the bottom of the hole, as a better explosive effect is thus obtained; but care must be taken, when tamping, that the insulating covering is not removed from the wires.

There are many types of blasting machines on the market, but those embodying the principle of a hand dynamo are preferable to the high tension friction machines which often refuse to work, especially in damp weather.

CHAPTER XXIX.

AERIAL WIRE ROPEWAYS AND WIRE ROPES.

Systems of Ropeways—The Otto Ropeway—Standards—Ropes—Carriers—Trucks—Friction Grip—Working—Angle and Power Stations—The Garucha Line—Aerial Ropeways—Bullivant's System in Pyrenees—Description and Cost of Working—Wire Ropes for Transmission of Power—Wire Ropes—Preservative Coating—Strength of Round and Flat Ropes—Splicing Ropes—Wire Rope Attachments.

Aerial Wire Ropeways.—The cost of transport of the ore from the mine to the mill, or of the dressed mineral from the mill to a port or railway station, is a question of vital importance, and is in many

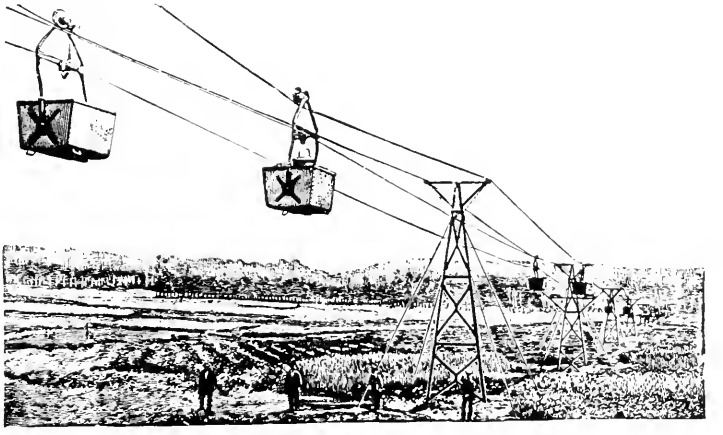


FIG. 344.—THE OTTO AERIAL ROPEWAY.

cases the sole reason for leaving mining properties undeveloped, or for the abandonment of undertakings of much promise. The great cost of ordinary railways, or even tramways, due in some cases to the value of the ground, and in others to its physical features, has led to the introduction of a new method of transport—the aerial wire ropeway.

Such a ropeway, by its long spans (in some cases of 1500 ft.), passes over all obstacles, while it hardly affects the value of the land, of which none need be purchased for permanent way. All that is required is the lease or user of a strip of ground, 10 ft. wide, which is occupied only at the points of support, and can otherwise remain in cultivation as usual.

The Otto Ropeway.—Aerial ropeways may be broadly distinguished as "one" and "two" rope systems: the former consisting of an endless running rope, which serves the dual function of carrying and hauling rope for the buckets. This system (which is connected with the names of Hodgson and Hallidie) is in use in America and Northern Spain; but in spite of its simplicity and cheapness it is surrounded with many

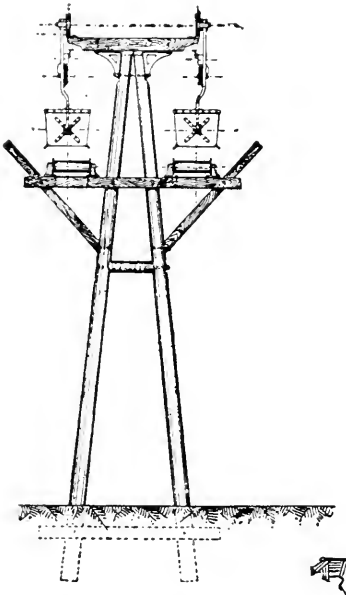


FIG. 345.—OTTO AERIAL ROPEWAY. WOODEN STANDARD.

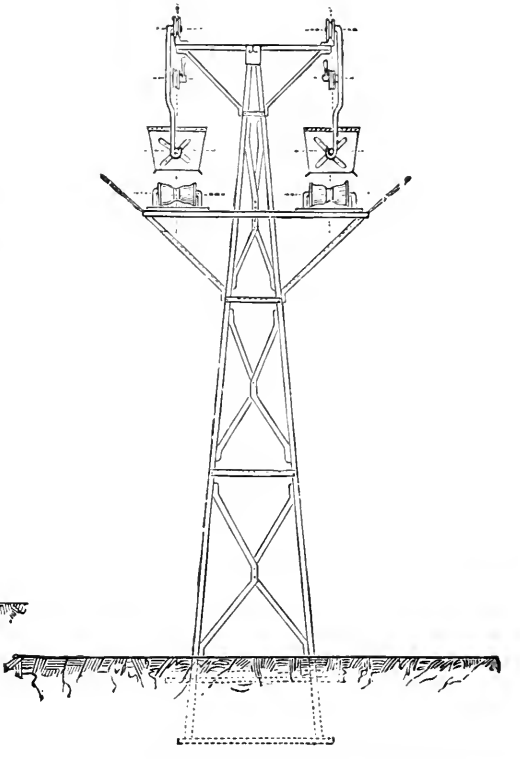


FIG. 346.—OTTO AERIAL ROPEWAY, IRON STANDARD.

difficulties in actual working. For this reason it is being superseded by the German or "two" rope system, which consists of the use of two ropes—a heavy fixed carrying rope and a light travelling hauling rope, to which the buckets are fixed by means of special gripping devices.

This latter is known as the Otto or the Bleichert system—by the names, that is, of two gentlemen who have been instrumental in bringing it to perfection. Their representative for England and the Colonies is Mr. R. E. Commans, M.E., of 6, Queen Street Place, London, E.C. (The "two" rope system of Messrs. Bullivant will be found described later on, pp. 525-528.) I myself have had some personal experience

abroad of the erection and working of the Otto system, in connection with a lignite briquette factory near Aix-la-Chapelle ; and I am informed that a line, two miles in length from station to station, has recently been set up for the transport of coal at a colliery near Durham.

The carrying capacity of the aerial ropeway has increased with the demands made upon it. Ten years ago the maximum loads were from 4 to 5 cwts. ; now, however, they vary between 10 to 20 cwts., so that the carrying capacity is now from 600 to 800 tons per day of 10 hours ; while there are ropeways in work of from 8 to 10 miles long.

The standards which support the ropes are usually placed at from 100 to 200 ft. apart, according to the configuration of the ground, of which a survey and section should be carefully made. The spans may, however, under special circumstances, be as great as 1500 ft., say, when crossing narrow valleys or rivers. The supports are made of wood or iron as shown in figs. 345 and 346, and are usually stayed with wire rope guides. When of wood the legs may be ordinary round poles, with the top cross pieces of well-seasoned oak. If built of iron the uprights are usually constructed of channel or I-beams, stiffened with angle iron, and the crosspieces are made of channel iron. For heavy loads and great spans the standards are constructed with four legs.

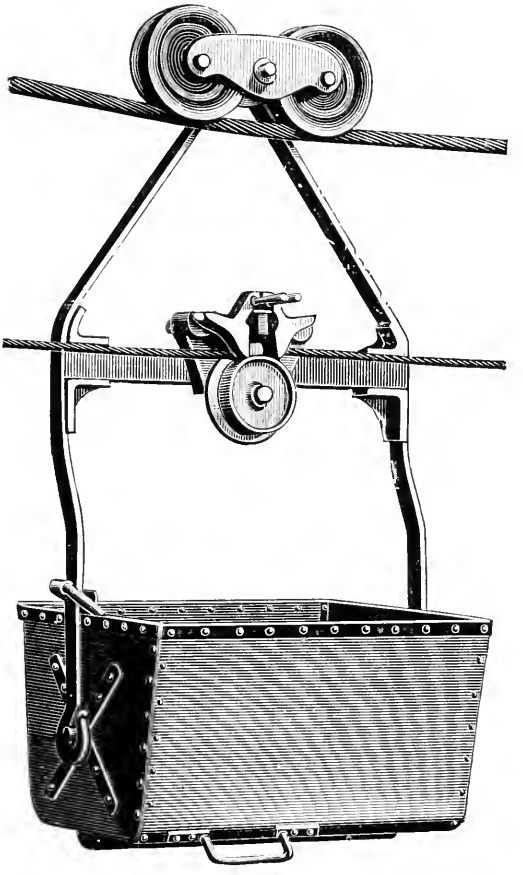


FIG. 347.—CARRYING BUCKET FOR AERIAL ROPEWAY.

As seen in the illustration, the fixed rope rests simply in an iron shoe, so constructed as not to offer any resistance to the passage of the wheels of the carriers. The buckets support the hauling rope at frequent

intervals; but when these are long the rope runs over the rollers fixed on arms projecting from the stavelards.

The carrying or fixed ropes are specially designed of stout steel wire, 4 to 7 mm. or $\frac{5}{32}$ to $\frac{9}{32}$ in. in diameter, which has a breaking strain of from 38 to 76 tons per square inch. The hauling ropes, on the other hand, in order to be as flexible as possible, are made with a hempen core and of fine steel wire, which has a breaking strain of from 76 to 114 tons per sq. in. The carriers are made in a great variety of designs.

For the conveyance of mineral sheet iron buckets are used, such as that shown in fig. 347, with special tipping arrangements.

The carriers are suspended from trucks or runners, such as that

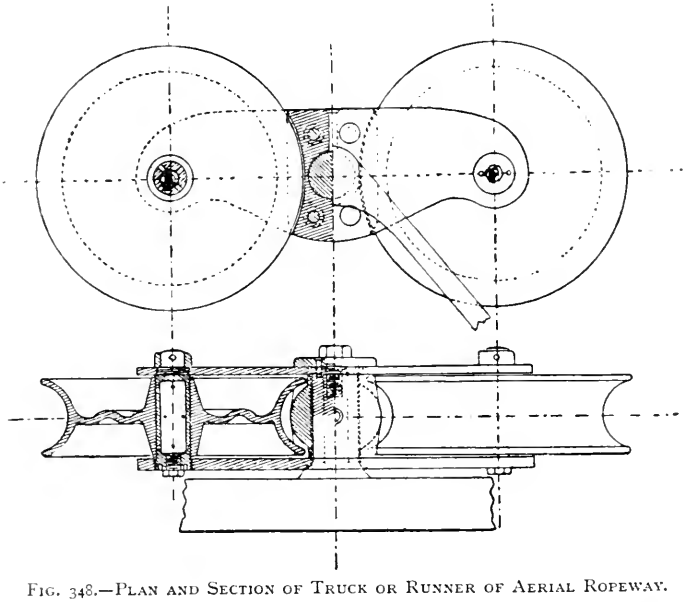


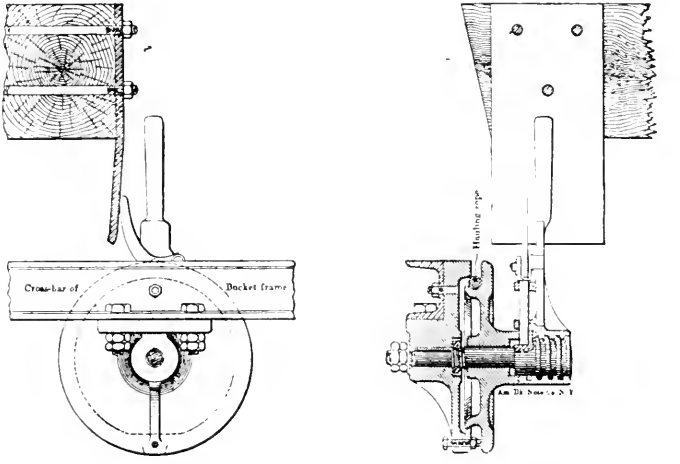
Fig. 348.—Plan and Section of Truck or Runner of Aerial Ropeway.

illustrated in fig. 348, which has been in use for over six years, and entirely overcome the faults of the earlier trucks, in which the spindles of the grooved wheels were supported on one side only. By supporting them on both ends the wheels are not liable to skew.

The frame of the truck consists of two steel plates connected in the middle by a cast iron distance piece, through which the spindle of the hanger passes, and at each end by a phosphor bronze distance piece, which forms the spindle for one of the grooved wheels. Each of these spindles is hollowed out to contain a lubricant. On removing the thumb-screw shown in the end, the lubricant passes through small holes to the surface of the spindle. By this system of lubrication the spindles and rollers are preserved for years from almost every sign of wear.

Another equally important detail is to ensure regular and uninterrupted working in the form of coupling or grip for attaching the carrier to the hauling rope. This must not only be simple in design, but absolutely reliable in its action, and should reduce the wear on the hauling rope to a minimum. The friction grip and the lock grip are the two forms usually employed. With the former, the carriers can be attached to the hauling rope at any point; with the latter, small collars or carrier knots have to be fixed at intervals along the hauling rope corresponding to the distance apart at which it is intended to attach the carriers.

The form of friction grip in general use is shown in figs. 349, 350, and consists of two smooth-faced discs—one rigidly attached to the cross bar of the hanger, and the other mounted loosely on a spindle and



FIGS. 349, 350.—DISC FRICTION GRIP OF AERIAL ROPEWAY.

free to revolve, acting, when necessary, as a carrying roller for the hauling rope. The spindle has a square thread on its outer end, and carries a lever, the boss of which forms the nut. When the lever is down the discs do not grip the rope, but are kept apart by a spring.

As it is raised the discs approach each other, and when up the hauling rope is tightly gripped. The lever is prevented from falling back by a small spring trigger. As the carrier bucket approaches a station, the lever and trigger both encounter a stop which throws them over, separating the discs and automatically releasing the hauling rope. The bucket is then free to be switched off the carrying rope. The discs can easily be adjusted, allowing for the size and wear of the rope.

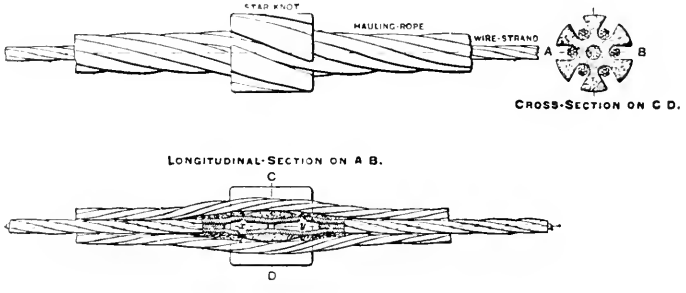
This form of grip is employed for gradients up to 1 in 6, and for loads of 9 cwt. net weight. For steeper gradients, up to 1 in 3, where a friction device is still practicable, a more powerful grip with corrugated

jaws is used instead of the smooth-surface discs. One of the jaws is rigid, while the other is moved in and out by means of a lever and cam, so as to grip the hauling rope. Both forms of friction grip have given satisfaction.

Since the buckets can be attached to the hauling rope at any point, the tendency to a uniform wear throughout the length of the rope is promoted, and this is a distinct gain. Another advantage in using friction grips is, that the carrying capacity of the line can be easily altered simply by adding more carriers at shorter intervals, without varying the travelling velocity of hauling rope, the speed of which is about $3\frac{1}{3}$ miles per hour.

For lines having gradients under 1 in 6 the disc grip is the best existing form, as it subjects the hauling rope to the least wear. In the case of the Fernie ropeway, erected in Giesen in 1879, the original hauling rope was still in regular work in 1891.

For gradients steeper than 1 in 3 a lock grip is absolutely necessary.

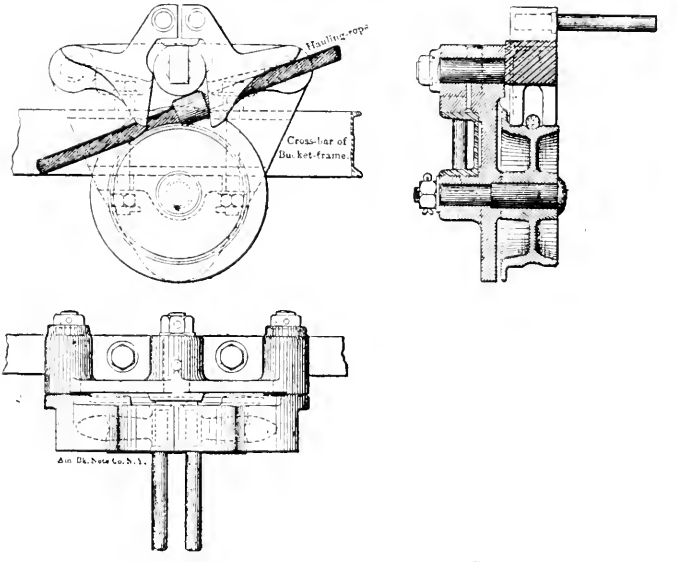


FIGS. 351, 352.—STAR KNOT ON HAULING ROPE OF AERIAL ROPEWAY.

The number of buckets and the corresponding capacity of the line for a given speed are then limited by the spacing of the knots on the hauling rope. The design of the knot is of almost as great importance as that of the grip itself; and perhaps the best is the "star" knot, illustrated in figs. 351, 352. It consists of a cylinder whose diameter is somewhat greater than that of the hauling rope, and whose surface is provided with spiral grooves into which the strands of the hauling rope are inserted. When the knot is in its place, its ribes project sufficiently beyond the hauling rope to furnish a hold for the pawls of the grip. In order to secure the knot in its position with absolute certainty a steel wire strand about 2 yds. long is passed through it and fixed by the two wedges (x and y). When the knot is to be attached to the hauling rope, the latter is first untwisted, and 2 yds. of the hemp core are removed. The knot and the steel wire strand, which takes the place of the hemp core, are then set into the rope, and when this has been twisted tight its hold upon the knot and strand is sufficient to resist any shock to which they may be subjected.

The grip best adapted for use when the steepness of the gradients requires knots on the hauling rope is the pawl grip shown in figs. 353 to 355, which is extremely simple. It consists of two symmetrically disposed pawls, each free to move on a vertical plane, and having forked ends which drop down on either side of the knot, the drop being checked by a stop. The rope is supported on a roller just below the pawls. To throw the pawls in and out of action the toe of each pawl carries a pin, which engages with a guide rail at the station.

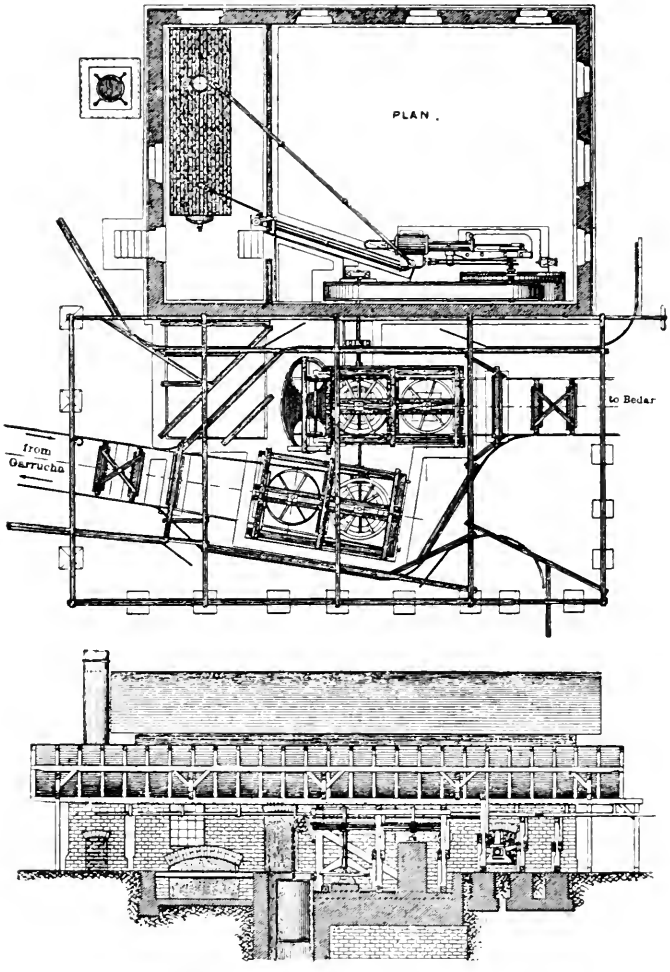
In coupling a bucket fitted with one of these grips, the workman moves the bucket by hand along the switch rail to the carrying rope; on approaching this the pawl pins come in contact with the guide rail,



FIGS. 353, 354, 355.—PAWL GRIP OF AERIAL ROPEWAY.

raising the pawls so as to allow the hauling rope to be guided, and rest on the roller, which is immediately below them, and forms part of the grip. As soon as the bucket rests on the carrying rope, the pins are released from the guide rail, and the pawls fall down in position over the hauling rope. As a knot approaches it lifts the first pawl, which, however, falls back into its original position; but the second one resists, and the bucket is automatically taken in tow. To avoid a violent impact, of the knot upon the coupling, the shunter gets a bell-signal when a knot is approaching, and he pushes off the bucket at about the same velocity as the rope is travelling. The uncoupling is similarly effected. As the bucket nears the station, the pawl pins come in contact with a guide rail, lifting the pawls out of gear, and releasing the hauling rope;

the bucket, by virtue of its momentum, then moves off the carrying rope, and up a tongued rail which switches it into a siding. This is probably the only lock-coupling constructed so as to be thrown in and out of

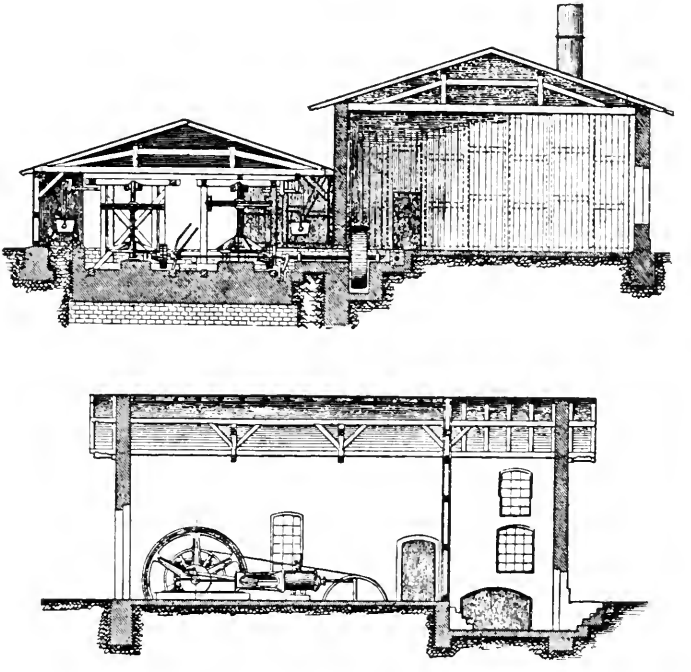


FIGS. 356, 357.—OTTO AERIAL ROPEWAY. PLAN AND SECTION OF ANGLE AND POWER STATION.

gear automatically, and successfully and safely used in transporting loads of more than one ton on mountain lines up gradients of 1 in 1.

The carrying ropes are firmly anchored at the terminal stations to masses of masonry, and are kept taut by means of tenon weights fixed at the angle stations, as shown in figs. 356 and 357, which represent a power

and angle station on the Garucha line in northern Spain. These angle stations are necessary in those cases where the ropeway cannot be constructed in a straight line from end to end. When the buckets arrive at an angle station they are automatically disengaged from the hauling rope, switched on to the shunt rails, and run round by hand to the carrying rope on the next section of the line, where they are again attached to the hauling rope and sent off in the new direction. The arrangement of the shunt rails and tenon weights of an angle station, with the hauling engine, is shown in plan and section in figs. 347 and



FIGS. 358, 359.—OTTO AERIAL ROPEWAY. SECTIONS OF ANGLE AND POWER STATION.

348. The power is transmitted by belt and gearing to two large grooved pulleys, lined with leather, about 7 ft. 3 in. in diameter, around which the hauling rope is several times coiled. This rope is kept taut by means of tension weights and pulleys similar to those of the carrying rope.

The Garucha line just referred to is one of the most important of the Otto ropeways yet constructed. It is used for the transport of iron ore from the mines at Serena de Bedar to the Mediterranean coast at Garucha, a distance of $9\frac{1}{2}$ miles. The line is divided into four sections, the first two of which are 1·40 and 3·29 miles long respectively, and are driven by means of a 30-horse-power engine;

and the second two sections are 3·29 and 2·8 miles long, worked by a 70-horse-power engine.

After leaving the loading station at Serena, which is over 905 ft. above the sea level, the line crosses a number of deep valleys, one of which is over half a mile wide and 328 ft. deep, and traverses mountain ridges, the highest of which is 1174 ft. above the sea level, to the village of Pendar de Bedar, where, at an elevation of 951 ft., the first power station is located.

From here the line deflects to the right, and again passes over several valleys and ridges, with a gradual descent to an angle station 370 ft. above the sea level. It then bears to the left, extending over a more or less hilly country to the second power station near Puerto del Coronel, of which a plan and sections are given in the preceding illustration (figs. 356 to 359). From this point the line turns to the right, and descends at an easy gradient to the unloading station on the coast near the town of Garucha.

The greatest span of the line near the Villa Reforma is 918 ft. wide, and here the rope sags 65 ft. and carries 6 loaded and 6 empty buckets at a time.

The other long spans of the line range from 328 ft. to 750 ft., but the average distance between the supports is only about 130 ft. The steepest gradient, taking into account the sag of the rope, is 1 in $2\frac{1}{2}$, and the tallest standard is 118 ft. high. The guaranteed capacity of the line is 400 tons per day of 10 hours. With a travelling rate of 300 ft. per minute, or about 3 miles an hour, and with two buckets of 7 cwt. capacity arriving per minute, or say 1200 buckets per day of 10 hours, the actual quantity carried by this line is 420 tons, making its capacity 4095 ton-miles. The line has been worked since the commencement of 1890 in two shifts of 8 hours, and no less than 900 tons per day have been transported to the coast.

The carrying ropes for the loaded and unloaded side respectively are $1\frac{5}{16}$ and 1 in. diameter, and the size of the hauling rope is about $\frac{3}{4}$ in. The latter is fitted with the star knots already referred to, and the pawl grips are used throughout.

At the loading station, bins of 800 tons aggregate capacity are erected, from which the ore is spouted into the buckets. The engine and boiler houses are solidly built, and are large enough to be used as repairing shops.

The unloading station at the coast is 150 ft. long × 50 ft. wide and 32 ft. above the ground level. Its storage capacity is from 18,000 to 20,000 tons, so that from 4 to 6 vessels can be loaded at a time. At the various stations sidings are arranged for stocking empty carriers from various sections of the line. Electric signals are used, and the the stations are connected by telephone. The line was surveyed,

constructed, and ready for work within 10 months, and its total cost was £26,000. The constructor of the line (Mr. J. Pohlig, of Cologne) contracted to work and keep the line in repair for a number of years at the rate of 1*s.* 2½*d.* (28·8 cents) per ton carried, this price to cover all the cost for labour, maintenance, and repairs.

Bullivant's Ropeways.—There are many other constructors of wire ropeways, amongst whom may be mentioned Messrs. Bullivant & Co., Limited, of London, of whose work I have had some years practical experience in the Pyrenees.

A member of the firm—Mr. W. Carrington, M.Inst.C.E.—has thus described * different arrangements of wire-rope transport:

"(1) The endless-running rope, as originally made by Mr. Charles Hodgson, now greatly improved in all details;

"(2) An endless-rope type of ropeway, with the carriers rigidly fixed in position on the rope;

"(3) The fixed-rope type, also patented by Mr. C. Hodgson, but now constructed with many improvements and alterations, differing in some details from those made in Germany;

"(4) The single fixed-rope type, in which one carrier is drawn to and fro by means of an endless hauling-rope;

"(5) The use of two fixed ropes, with an endless hauling-rope, in which one carrier travels in one direction while the other runs on a parallel rope in the opposite direction."

These various types of ropeways he further discusses as follows:

"(1) *Endless-running Rope.*—Respecting the running-rope type, the author considers that it is most suitable under the following circumstances: Where the quantity to be carried does not exceed 400 to 500 tons per 10 hours, where the inclines do not exceed 1 in 3, and where the individual loads do not exceed 6 cwts., and also where the section of ground does not necessitate spans of greater length than 600 ft. Longer spans, steeper inclines, greater quantities, and heavier loads can be carried by this system, but not so advantageously, in the author's opinion, as by another system referred to hereafter.

"(2) *Endless-rope Type.*—The second type is similar in some respects, and is specially suitable where very steep inclines and sudden and continual changes of level have to be operated over. It is probably impossible to state the limit of incline on which this type of ropeway can work. As guard- or depressing-pulleys may be placed wherever necessary without obstructing the passage of the carriers, the vertical angle of the line may change at each post. It has the driving-gear, the tightening-gear, and the endless-rope, also the pulleys, but the position of the carriers, therefore, is fixed; they are placed in position, and where

* In a paper read before the Federated Institution of Mining Engineers, 1901.

the rope goes they must go. As a result, at the terminals they must go round the terminal-wheels.

"(3) *Fixed-rope Type.*—The third type of ropeway is that in which two parallel fixed-ropes are used on which the carriers run drawn along by means of a hauling-rope. It should be employed where the quantities to be transported exceed 500 tons per day, except in the case where grouped lines of the first type are suitable, and where the loads exceed 6 cwt., also where the inclines exceed 1 in 2 or 3, and spans are over 600 to 1000 ft. It is economical in wear-and-tear, but the first cost is great, and it does not lend itself to sudden changes in the vertical angle of the line, but where the quantities to be transported are not large the fourth and fifth type may be found superior.

"(4) *Single Fixed Ropes.*—The fourth type or single fixed rope with one carrier is most suitable for situations where moderate quantities have to be transported, and for heavy individual loads and over great spans and steep inclines it is cheaper in first cost and maintenance than the third type, and simpler to erect and to manipulate. The arrangement consists of one single fixed rope in which one carrier is employed, this carrier being drawn to and fro by suitable motive power.

"(5) *Two Fixed Ropes.*—The fifth and last type is one which acts as an intermediate between the third and fourth, being most suitably used where the quantity is not sufficient to justify the use of No. 3 type or where the loads are too heavy; also where the spans are extremely long and great simplicity of detail is desirable. It is cheaper than the third type, both as to first cost and to maintenance, and requires fewer men to manipulate it."

This last-mentioned system (No. 5) is the one with which I am personally acquainted. Its main feature is the use of *two fixed ropes*, with an endless hauling rope, in which one carrier travels in one direction, while the other runs on the parallel rope in the opposite direction. This is a thoroughly serviceable type of tramway, capable of being used over extremely long spans and of carrying loads up to 5 tons. It lies between the third and fourth systems above referred to, adopting the use of two parallel fixed ropes as in the third system, but with the use of one carrier on each rope as in the fourth system.

It may be used where the quantities required to be moved are such as will admit of the ropeway being worked by gravity, one carrier descending loaded, while the empty carrier ascends unloaded. With this arrangement spans up to 2000 yds. may be made without supports, loads up to 6 tons may be carried, and quantities up to 100 tons per day transported. In other cases steam power may be employed, and the loads moved from the lower to the upper terminal, while the empty carrier descends loaded or unloaded as may be the case.

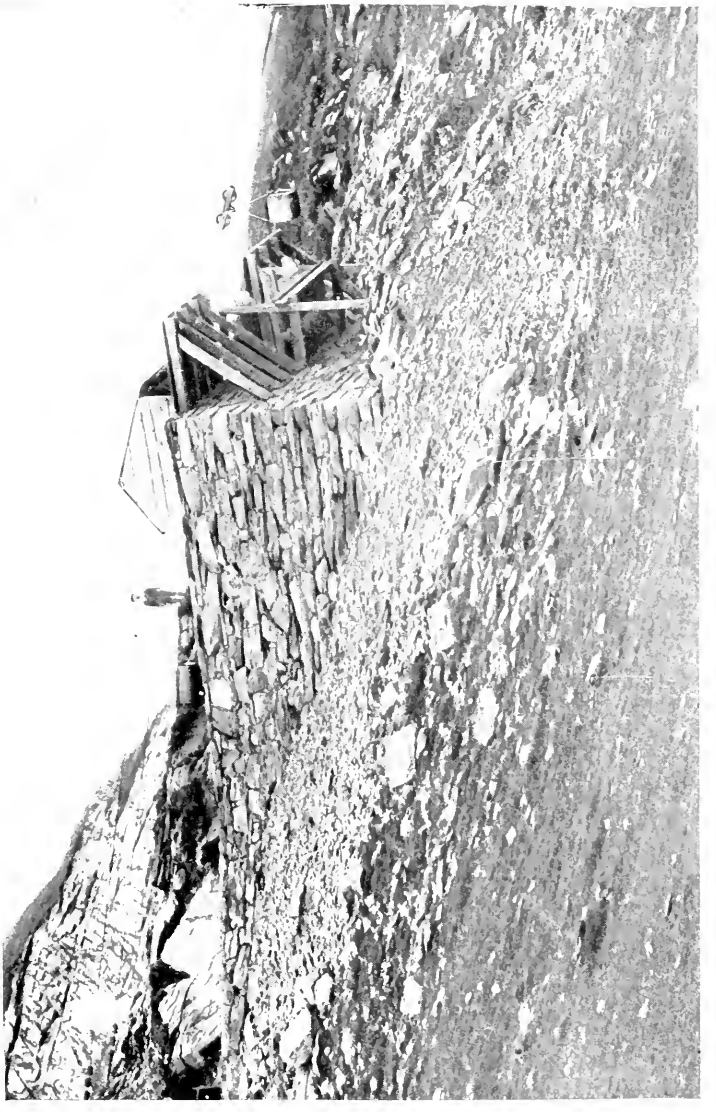


Fig. 360.—Upper Terminal of Aerial Ropeway.

To face page 210.

Fig. 361.—Lower Terminal of Aerial Ropeway.

To face page 520, after PLATE XXVII.

By the experience gained in the construction of a number of such ropeways, great efficiency has now been arrived at, so much so that these ropeways may be relied upon to provide a safe means of transport for passengers as well as goods, and the speed at which the carriers run not infrequently amounts to 30 or 40 miles per hour. The control of the line is effected by a brake gear situated at the upper terminal, operated by one man who can perfectly regulate the speed.

While many ropeways on this system are employed simply to span from the upper portion of a mountain over a valley to the lower side of another, others are constructed with one or more supports, and skirt the side of a steep hill. In this latter case a slower speed must be maintained, not above 10 miles per hour, as the passing of the carriers over the supports at a higher speed is inadmissible. As the loaded carrier is usually much heavier than is necessary to draw up the empty one, a proportionate amount of material may be transported up as well as down; indeed, in some cases, where water is available, it is possible to run materials up alone, employing the descending carrier as a counterbalance filled with water. Where loads are required to be carried up the incline and not down, and steam power is supplied, ropeways of considerable efficiency have been constructed; in this case an engine or other motive power operates a driving gear at the lower terminal, and a carrier containing the necessary passengers or materials to be transported moves at a speed of 8 to 10 miles an hour up the incline, while the empty carrier descends loaded or unloaded as the case may be.

A series of five ropeways constructed on this system, and operated only by gravity, have been installed in the Pyrenees. Two illustrations thereof are given in Plates XXVII. and XXVIII., the span there shown being one of 1000 yds., on which carriers holding 10 cwt. are run. By means of this chain of ropeways, minerals are brought by five stages from a mine 6500 ft. above the sea to a depôt 3500 ft. lower down. Each section requires three men to attend to it, and can send down 10 tons of ore per hour.

At the Pierrefitte mines, where is situated the ropeway on the system just described, of which I have had experience, the longest span is 738 metres. The ropeway itself, for convenience of loading at the different levels of the mine, is divided into two sections. At the upper end of each section there is a drum and brake wheel contained in a small wooden building, such as shown in fig. 360 (Plate XXVII.). The ore trammed from the mine is tipped into hoppers from the mouths of which it falls into the buckets of the aerial ropeway. The standing cables which are $1\frac{1}{2}$ in. diameter are anchored securely to the rock behind, while the running cable to which the buckets are attached is controlled by the brake. At the lower end of the upper section the

buckets are emptied, as are also the waggons coming from the mine at that level into hoppers feeding the buckets of the long lower section which terminates at the "grizzleys" feeding the rock-breakers and feeding belts of the concentrating mill. The lower terminals are constructed as shown in fig. 361 (Plate XXVIII.), and the standing ropes may either be stretched by counterbalance weights hanging in a pit or when required by the blocks and winches shown.

A trailing cable, not shown in the illustrations, connects the rear of the two buckets in order to keep them always in the same relative position and insure their arrivals at exactly fixed points. This is only a light steel rope, and is not so heavy as the hauling cable. This rope-way which is one of the earliest constructed has been running for over 10 years, and the only trouble ever experienced is due to the expansion and contraction of the running ropes, which require a little adjustment at changes of the season. The average load is about $\frac{1}{2}$ a ton.

Transmission of Power.—It frequently happens in laying out the design for a mill that the source of water-power is situated at some little distance from the site of the mill; not so far as to necessitate the use of electricity as a means of transmission of power, and yet at such a distance as to create some little difficulty as to its application.

If this distance is under a mile, the most economical and simple method of overcoming the difficulty is by the use of wire rope running in V-grooved pulleys. The pulleys are made of cast iron or steel of as great a diameter as possible, in order to avoid the loss caused by the bending of the rope over a small pulley, both in friction and in wear and tear of the rope. Wheels over 8 ft. in diameter are made in sections, and the groove is always lined with leather or other soft material. The rope travels at a speed of about 80 ft. per second. The distance to be traversed is divided into sections according to the configuration of the ground; and at each section a pair of wheels keyed to one shaft is erected on a suitable foundation of wood or masonry. The one wheel receives the power from the preceding station by means of the wire rope, which takes the place of an ordinary leather belt, while the other transmits it by another rope to the succeeding station, and so on until the mill is reached.

The approximate cost of such a system for the pulleys, bearings, wire ropes, etc., necessary for transmitting 50 horse-power a distance of 3000 ft. would be about £800, and for 100 horse-power, the same distance, about £1200. These figures do not include the cost of erection or of the prime motor engine or turbine.

The efficiency of such a system diminishes with the number of stations employed, and according to Stahl is as follows:

Number of Intermediate Stations.	Efficiency of System.	Per cent. of Power Wasted.	Number of Intermediate Stations.	Efficiency of System.	Per cent. of Power Wasted.
0	0·962	3·8	3	0·908	9·2
1	0·944	5·6	4	0·890	11·0
2	0·925	7·5	5	0·873	12·7

The use of wire ropes for the transmission of power is, however, limited to short distances, for which it compares favourably with other methods. Practically it may be said that electric transmission will, in the future, supersede all other means, as being the most economical and efficient; and with this I have dealt in Chapter XXVII.

Compressed air can be, and is indeed used for the same purpose, and has the great advantage of being useful for ventilation after it has been deprived of its power. In metalliferous mines this is perhaps of not so great importance, but in collieries, where every additional cubic foot of air is of value, the exhaust from pumps and hauling engines driven by compressed air is especially welcome, and is delightfully fresh and cool as compared with the hot, dust-laden air which has circulated through miles of roadways.

From this point of view, compressed air as a means of transmission of power appears to great advantage; but, on the other hand, when all the losses due to compression, friction in and leakage of pipes, and reconversion into power, are taken into consideration, it does not compare favourably with electricity. (See Chapters VII. and VIII. of this work, which treat of Compressed Air as applied to Rock Drilling.)

The efficiency of a well installed compressed air system is about 33 per cent. which is considerably inferior to an electric installation.

Wire Ropes.—Wire ropes are so extensively used in mining for transport and other purposes, that a few observations will not be out of place as to their strength, durability, and maintenance.

They are usually made of six strands laid about a centre core of hemp or wire, the former being more pliable, and wearing better over small drums and pulleys, although it conduces to the longevity of the rope that these should be of as great a diameter as possible. The strands are each composed of nineteen wires, where great flexibility is required, as for hoisting ropes, and of seven or twelve wires for stiffer ropes, as those used for guys, ferries, rigging, and transmission purposes.

Wire rope is as pliable as hemp rope of the same strength, but care should be taken not to coil it for storage, or uncoil it in the same manner as with hemp rope. To prevent it from kinking, it should either be wound on a reel or rolled upon the ground like a wheel.

Galvanised wire rope should not be used as a running rope, as the

coating of zinc would wear off in a day's work, and the exposed wires soon begin to rust.

To preserve wire ropes from the action of the weather they should be thoroughly coated with a mixture of raw linseed oil and vegetable tar. For wet places and underground work the rope should be saturated in a hot mixture, made by boiling a barrel of mineral or vegetable tar, and adding thereto a bushel of fresh slaked lime.

The wear of the rope may be greatly reduced, and its life lengthened, by attention being paid to the surfaces of the pulleys, sheaves, drums, etc., over which it is run. The grooves should be lined with well-seasoned blocks of hard wood set on end, rubber, leather, or some soft metal, thus securing not only greater adhesion but also reducing the wear.

The safe working load may be fixed at from one-fifth to one-seventh of the ultimate strength, according to the speed and vibration. It is better to increase the load than the speed, as the latter increases the wear.

The following tables give the sizes, weight per fathom, and the breaking and loading strain for round and flat ropes:

ROUND ROPES.

Sizes.		Weight per Fathom.	Plough Steel.		Patent Steel.		Iron.	
Circumference.	Diameter.		Breaking Strain.	Working Load.	Breaking Strain.	Working Load.	Breaking Strain.	Working Load.
inches.	inches.	lb.	tons.	cwt.	tons.	cwt.	tons.	cwt.
1	$\frac{5}{16}$	1	4	8	3	6	1	2
$1\frac{1}{4}$	$\frac{3}{8}$	2	7	14	5	10	2	4
$1\frac{1}{2}$	$\frac{15}{32}$	$2\frac{1}{2}$	10	20	6	12	3	6
$1\frac{3}{4}$	$\frac{9}{16}$	3	13	26	8	16	4	8
$1\frac{7}{8}$	$\frac{19}{32}$	$3\frac{1}{2}$	15	30	9	19	$4\frac{1}{2}$	9
2	$\frac{5}{8}$	4	17	34	11	22	5	10
$2\frac{1}{4}$	$\frac{23}{32}$	5	22	44	15	30	7	14
$2\frac{3}{8}$	$\frac{3}{4}$	$5\frac{1}{2}$	24	48	16	32	8	16
$2\frac{1}{2}$	$\frac{25}{32}$	6	27	54	19	38	9	18
$2\frac{5}{8}$	$\frac{13}{16}$	$6\frac{1}{2}$	30	60	20	40	12	24
$2\frac{3}{4}$	$\frac{27}{32}$	7	33	66	23	46	13	26
3	$\frac{15}{16}$	$8\frac{1}{2}$	37	74	27	54	15	30
$3\frac{1}{4}$	$1\frac{1}{16}$	10	47	94	29	58	17	34
$3\frac{1}{2}$	$1\frac{1}{8}$	11	56	112	34	68	19	38
$3\frac{3}{4}$	$1\frac{3}{16}$	13	63	126	41	82	22	44
4	$1\frac{1}{4}$	15	71	142	47	94	25	50
$4\frac{1}{4}$	$1\frac{5}{16}$	17	85	170	54	108	28	56
$4\frac{1}{2}$	$1\frac{3}{8}$	19	92	184	60	120	31	62
$4\frac{3}{4}$	$1\frac{7}{16}$	21	99	198	67	134	36	72
5	$1\frac{1}{2}$	24	107	214	78	156	42	84
$5\frac{1}{4}$	$1\frac{9}{16}$	27	119	238	83	166	46	92
$5\frac{1}{2}$	$1\frac{5}{8}$	30	130	260	89	178	50	100
$5\frac{3}{4}$	$1\frac{3}{4}$	$32\frac{1}{2}$	138	276	97	194	52	104
6	$1\frac{7}{8}$	35	148	296	107	214	59	118

The above weights are for hemp cores in strand and centre of rope; if wire cores weight will be about one-seventh more.

Flat Wire Ropes.

Breadth.	Weight per Fathom.	Plough Steel.		Patent Steel.		Iron.	
		Breaking Strain.	Working Load.	Breaking Strain.	Working Load.	Breaking Srain.	Working Load.
inches.	lb.	tons.	cwt.	tons.	cwt.	tons.	cwt.
$2\frac{1}{2} \times \frac{1}{2}$	12	47	94	32	64	16	32
$2\frac{3}{4} \times \frac{5}{8}$	14	54	108	38	76	18	36
$3 \times \frac{5}{8}$	16	74	148	50	100	23	46
$3\frac{1}{4} \times \frac{5}{8}$	18	81	162	56	112	25	50
$3 \times \frac{7}{8}$	20	93	186	61	122	30	60
$3\frac{3}{4} \times 1\frac{1}{16}$	23	111	222	72	144	32	64
$4 \times 1\frac{1}{16}$	25	120	240	83	166	36	72
$4\frac{1}{4} \times \frac{3}{4}$	29	126	252	90	180	44	88
$4\frac{1}{2} \times \frac{3}{4}$	31	140	280	102	204	53	106
$4\frac{1}{2} \times \frac{7}{8}$	34	148	296	106	212	61	122
$5 \times \frac{7}{8}$	37	160	320	110	220	69	138
$5\frac{1}{2} \times 1\frac{1}{16}$	38	163	326	119	238	70	140
6×1	40	168	336	120	240	75	150

The above weights are for hemp cores in strand and centre of rope; if wire cores weight will be about one-seventh more.

Flat ropes are frequently preferred for hoisting purposes, as, owing to their being coiled one layer above the other on the winding drum, the

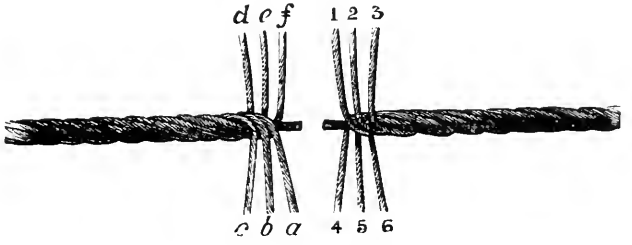


Fig. 362.—Splicing Wire Rope.

motion of the engine is balanced; the one drum being of small diameter when the heaviest weight of the rope is upon it, and the other of large

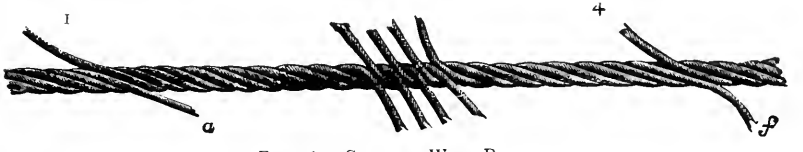


Fig. 363.—Splicing Wire Rope.

diameter when the cage is at the top of the shaft, and but little rope paid out.

This compensation cannot be effected with round ropes unless conical drums are employed.

Fig. 364.—Splicing Wire Rope.

Splicing Ropes.—The best form of rope for splicing is that made with six strands, as the strands are then the exact size for the core of rope, and are readily substituted for the core as it is being pulled out to allow the strands to take its place.

Five-strand ropes are also frequently spliced, and will hold more firmly than the six-strand rope, owing to the strands being a little larger than the core in the rope, so that when the splice is completed the outside strands press or grip more firmly upon the inserted strands, and thus prevent the possibility of the splice drawing; but when these ropes are bent round small diameters in the course of working the inserted strands are apt to protrude.

In splicing wire rope the greatest care should be taken to leave no projecting ends or thick parts in the rope. Heave the two ends taut, with block and fall, until they overlap each other about 20 ft. Then open the strands of both ends of the rope for a distance of 10 ft. each; cut off closely the main heart or cores (see fig. 362), and then bring the open bunches of strands face to face, so that the opposite strands interlock regularly with each other.

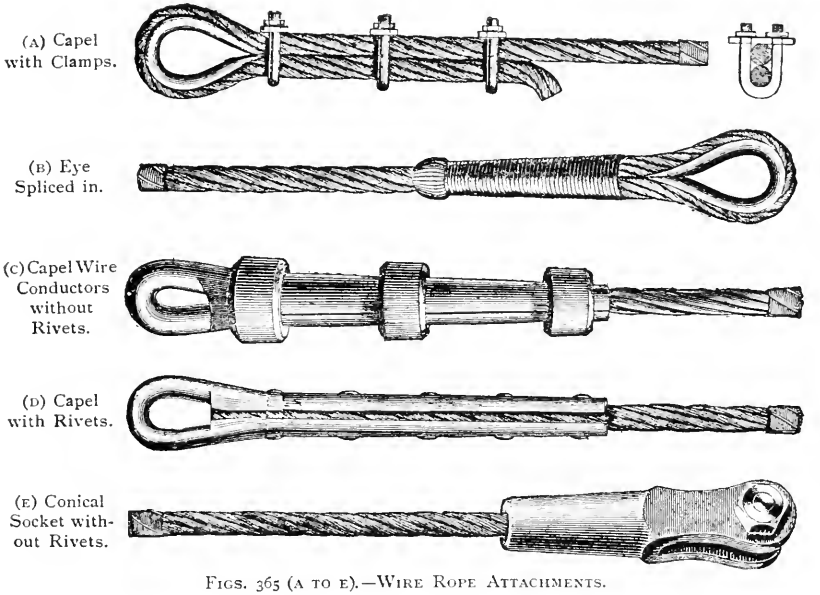
Secondly. Unlay any strand (A) follow up with strand (1) of the other end, laying it tightly into the open groove left upon unwinding (A) and making the twist of the strand agree exactly with the lay of the open groove, until all but about 6 in. of 1 are laid in, and A has become 20 ft. long. Next cut off A within 6 in. of the rope (see fig. 363), leaving two short ends, which should be tied temporarily.

Thirdly. Unlay a strand (4) of the opposite end, and follow up with the strand (F) laying it into the open groove, as before, and treating it precisely as in the first case (see fig. 362). Next pursue the same course with B and 2, stopping, however, within 4 ft. of the first set; next with E and 5; also with C, 3, and D, 4. We now have the strands laid into each other's places, with the respective ends passing each other at points 4 ft. apart, as shown in fig. 364.

Fourthly. These ends must now be secured and disposed of without increasing the diameter of the rope in the following manner: Insert marlinspike through the centre of rope, and cut out 6 in. of main core, and place the end

of 1 under A into the place occupied by the core, and then cut out the core in the same way on the right, and place the end of A into the place of the core in like manner. The ends of the strands should be straightened and lapped with fine hemp seizing before being put in. Then dispose of the remaining ends alternately in the same manner. After having done this the rope should be well closed, and any unevenness or irregularity can be taken out by pounding it with a wooden mallet.

In cases where ropes are heavily worked, when tucking in the ends, pass No. 1 over A, and B over No. 1. This mode of splicing ensures a very tight grip, and has been found to answer admirably.


(A) Capel with Clamps.
(B) Eye Spliced in.
(C) Capel Wire Conductors without Rivets.
(D) Capel with Rivets.
(E) Conical Socket without Rivets.

FIGS. 365 (A TO E).—WIRE ROPE ATTACHMENTS.

The wire rope attachments in ordinary use are shown in figs. 365 (A to E). In A the end of the rope is simply bent around a gimbal ring, and then covered with clamps. B is very neat in appearance, but cannot be effected except by skilled workmen. C, D, E are made by, first of all, enlarging the end of the rope to a conical shape—best effected by turning back the wires layer by layer, and binding them down with copper wire, and as the first layers are longer than each succeeding layer, the desired conical shape is obtained. The ring is made with long tapering ends fitting closely to the rope, and over these three iron rings are driven while hot, which tighten in shrinking. In D rivets are used instead of the rings; and in E the rope is run through the solid iron head until its cone-shaped head fits into the cone bored out of solid lead.

CHAPTER XXX.

TRANSPORT BY RAIL AND ROAD.

Useful Labouring Force of Man—Units of Work—Day's Work for a Man—Tramming Horse Traction—Loss by Friction over Road and Rail—Approximate Day's Work for a Trammer—Approximate Day's Work for a Horse—Inclines—Gauge—Rails—Sleepers—Portable Railway Plant—Laying the Line—Weight of Metal—Points and Crossings—Tram Waggons—Side-tipping Waggons—Traction Engines—Hill Climbing Power—General Arrangements—Cost of Traction—Cost of Engines—Thorneycroft's Steam Lorry.

THE question of transport is one which is intimately connected with that of successful mining, and is, indeed, often the crucial point which decides the continuation of the work at a mine, or its abandonment.

I have already, in Chapters XXVII. to XXIX., described the appliances used for electric haulage and aerial tramways; and in this, the last chapter of my work, I purpose indicating briefly the arrangements connected with tramways as applied to mining, and also transport by means of road locomotives or traction engines.

Tramways.—The use of tram rails and waggons is now so universal in mining that we need not refer to the older methods of carrying the ore in baskets on the head, nor, indeed, to transport in panniers on mule or horseback, which hardly come under the head of machinery; and will therefore pass on to consider first the amount of work which can be done by tram-waggons propelled by manual and horse-power, and afterwards the appliances used for the purpose.

The useful effect or labouring force of a man working under varying conditions is clearly shown in the subjoined table (from Morin), in which the unit of work is one pound avoirdupois, raised vertically one foot per minute.

The units of work are obtained by multiplying in the height in feet by the weight in pounds; thus the units of work in raising 200 lb., 50 ft. high = 200 × 50 = 10,000. The units of work done in raising a weight up an inclined plane are equal to the work done in raising a weight vertically through the height of the plane.

Labouring Ten Hours per Day.*

	Units of Work.
Raising materials with a wheelbarrow on ramps	720
Throwing earth to the height of 5 ft.	470

Labouring Eight Hours per Day.

Raising his own body	4250
Working with his arms and legs, as in rowing	4000
Working the treadmill	3900
Drawing or pushing horizontally	3120
Turning a handle	2600
Pushing and drawing alternately in a vertical direction	2380

Labouring Six Hours per Day.

Raising material with a pulley	1560
,, ,, the hands	1470
,, ,, upon the back	1126

Example: How many tons of rubbish would two men haul with a jack-roll from a sinking pit, whose depths is 15 yds., in 8 hours?

By the table, we see that a man turning a handle would perform 2600 units of work in a minute.

Then $2600 \times 60 \times 8 \times 2$ = work done, and to find the tons raised we must divide by number of pounds in a ton multiplied by the depth in feet thus—

$$\frac{2600 \times 60 \times 8 \times 2}{2240 \times 45} = 24{\cdot}76 \text{ tons.} \quad \textit{Answer.}$$

On this subject we give some information from the "Glossary of Terms used in the Coal Trade of Northumberland and Durham," article "Barrow-man":—

"The average day's work of a barrow-man or trammer who, when putting alone, is a young man from seventeen to twenty or twenty-one years of age, is equal on a level road laid with bridge rails, and with tubs having flanged wheels 10 in. diameter, to—

"One empty tub = 3 cwt. pushed 8280 yds. or ·7057 tons pushed 1 mile, or	8,346,240 lb. pushed 1 ft.
"One full tub = 10 cwt. pushed 8280 yds., or 23·523 tons pushed 1 mile, or	27,820,800 ,,
"Total day's work: 3·0580 tons pushed a distance of 1 mile, or	36,167,040 ,,

"And, taking friction at $\frac{1}{6\cdot5}$ part, the mean permanent force exercised by the barrow-man for 12 hours is equal to 556,416 lb. raised 1 ft. in 12 hours, or 773 lb. raised 1 ft. in 1 minute."

A horse-power, according to Boulton and Watt—the recognised standard—is 33,000 units of work done in 1 minute.

According to practical results, a horse drawing a coach can travel

* "The Colliery Manager's Pocket-Book" (1871).

10 miles an hour for one hour and carry a load of 10 cwt. A dray horse can travel $2\frac{1}{2}$ miles an hour, or 16 miles per day, frequently drawing 2 tons, including the cart. Hence the power in the one case is as the square root of the speed in the other; or the law of quantity of work done is as the square root of the velocity—the latter taking four times the weight of the former nearly double the distance. The traction, or force with which animals pull, decreases with the increase of speed Tredgold exhibits their relations as below:

Rate per hour.	Traction.
2 miles	166 lb.
3 ,,	125 ,,
$3\frac{1}{2}$,,	104 ,,
4 ,,	83 ,,
$4\frac{1}{2}$,,	$62\frac{1}{2}$,,
5 ,,	$41\frac{2}{3}$,,

The amount of useful work performed by either man or horse in pushing or drawing a loaded truck depends very largely upon the road over which the weight has to be moved, and the consequent friction offered by the material and state of repair of the road.

The following table will show the loss thus incurred, and will illustrate the diminution of labour in proportion to the perfection of the road or railway:

EXPERIMENTS SHOWING FRICTION ON VARIOUS ROADS.*

	Of the whole Weight.
Loose, sandy soil	Friction = $\frac{1}{5}$.
Turnpike road newly gravelled	,, = $\frac{1}{7}$.
Ordinary byeroad	,, = $\frac{2}{19}$.
Hard compact loam	,, = $\frac{1}{19}$.
Dry hard turf	,, = $\frac{1}{29}$.
Turnpike road with dirt	,, = $\frac{1}{29}$.
,, ,, free from dirt	,, = $\frac{1}{36}$.

EXPERIMENTS SHOWING FRICTION ON VARIOUS TRAMWAYS AND RAILWAYS. †

	Of the whole Weight.
On colliery railways	Friction = $\frac{1}{240}$.
On underground tramways with $11\frac{1}{2}$-in. wheels, with the road in good condition and round top rails	,, = $\frac{1}{109}$.
On underground tramways with rails worn at the top or flat-top rails, and with road in ordinary condition	,, = $\frac{1}{82}$.
On ordinary underground tramways with $7\frac{1}{2}$-in wheels	,, = $\frac{1}{53}$.

The friction of a railway tram is from 8 to 10 lb. per ton, or $\frac{1}{224}$ to $\frac{1}{280}$

* By Mr. Alexander Gordon † By Mr. Nicholas Wood.

of the whole weight. In the best constructed carriages it is perhaps as little as $\frac{1}{400}$ to $\frac{1}{500}$.

The above figures show the great importance and saving in labour to be effected by having tram roads laid and maintained in the best possible manner. Underground, owing to the sharp curves, it is often difficult to maintain the road in good condition, but on the surface no such excuse is valid, and there is no reason why the surface tram-roads connecting a mine with the mill or shipping port should not be laid down in the first instance with as much care as to curves, gradients, and permanent way as a regular narrow-gauge road designed for passenger traffic.

Men.—The approximate daily work which a man can perform on a level railway may be obtained on the basis that a man can move a waggon containing 12 cubic ft. of earth, equal to 10 cwt., at a speed of $1\frac{3}{4}$ mile per hour, returning with the empty waggon at a speed of $3\frac{3}{4}$ miles per hour. Taking an average speed of $2\frac{1}{4}$ miles per hour, a man in a day of 10 hours could therefore move about 60 tons weight of earth a distance of 200 yds., being about ten times as much as could be done by a navvy with a wheelbarrow.

Horses.—Horses can be advantageously employed, both on the surface and underground tramlines, and the amount of useful work they will do will depend upon the state of the roads, the construction of the trams, and the siding arrangement. The road intended for a watercourse need not have a fall of more than 1 in 250 to 200, but the inclination at which a horse will do the largest amount of work is when the resistance is the same in both directions, the fall being with the load, which may be something steeper. It is likewise in favour of horse-work to have the roads straight, to avoid sharp curves, and to have the gradient regular. With regard to the tram wheels, as the friction of them is in inverse proportion to the diameter, large wheels are preferable to small ones when height will admit of their use. With the roads and trams both good, and proper siding accommodation, and no delays at the end of the journeys, it may be calculated that a horse will do a fair amount of work, and this may be summed up as follows:

On a level railway a horse can draw seven waggons loaded with earth, each containing about 20 cubic ft., equal to 7 tons weight, at an average speed of $2\frac{1}{2}$ miles per hour. A horse can thus move about 70 tons, a distance of one mile, by making ten trips with loaded waggons, and returning empty, as a day's work on a level railways, whereas on an ordinary road with a two-wheel cart a horse could not do more than one-tenth of the work in the same time.

Tramway Construction.—*Wheels.*—The question as to whether the tram wheels should be fixed or loose upon their axles, is one upon which much might be written both for and against. Generally speaking,

however, it may be said that loose wheels are better adapted to running on the tortuous roads underground where the curves are sharp, and on the other hand fixed wheels are to be preferred for work upon the surface roads, where the conditions more nearly resemble those of a railway.

Self-acting inclines, on which the loaded trucks descending haul up the empties, are in frequent use both on the surface and underground, and to these the following remarks apply.*

To find the gradient at which the full tubs on an incline will balance the empty ones—

Let L = Full load,
E = Empty,
F = Friction,
and x = Gradient,
Then $F \times \frac{L + E}{E - L} = x.$

We think, however, we are not far wrong in stating that inclines underground will not work under a gradient of 2 in. per yard, or 1 in 18.

The empty trams on an incline will draw out the rope from a stationary engine, when the fall is about 1 in 28; but not a less inclination, unless, indeed, the friction be reduced to a minimum.

"The above remarks apply only to the case of *tramways*; on *railways*, the friction being, generally speaking, less than one-half, inclines will work at a less gradient. According to Mr. B. Thompson, eight laden chaldron waggons, descending a plane of $\frac{5}{8}$ in. per yard (1 in $57\frac{3}{5}$), will bring up eight empty ones at a good working speed. Six laden waggons require a fall of $\frac{3}{4}$ in. to the yard (1 in 48), and four laden waggons require $\frac{7}{8}$ in. to the yard (1 in $41\frac{1}{7}$).

Gauge.—The question as to the most suitable gauge for the tramways in and about a mine is usually decided by local conditions, such as the gauge in use at neighbouring mines, or the stock of the manufacturer who supplies the waggons, the weight of the mineral, etc. The narrowest gauge in successful use on a large scale is probably 1 ft. $11\frac{1}{2}$ in., the gauge of the Festiniog Railway, constructed for the purpose of conveying slates and passengers from Festiniog to the Port of Portmadoc. Locomotives are used for traction, and after leaving the main line the waggons are hauled up the self-acting inclines into the quarries. Tramways are laid with gauges only 18 in., which may be taken as the minimum, the maximum being a 36 in., or say a metre gauge, beyond which size the line comes under the category of a railway.

Rails.—The rails used are either those known as "bridge," the single-headed flange rails, or the double-headed rail, which is rarely employed in mines as it involves the use of chairs. The bridge and

* "Colliery Manager's Pocket Book."

flange rails are secured to wooden sleepers, placed about a yard apart by means of stout nails or "dogs." The joints are made by simply nailing down the abutting ends on a somewhat broader sleeper, though, for permanent work with flange rails, fishplates should be used.

The weight of rail per yard depends upon that of the load to be carried, and the gauge. It is always advisable, however, to have a heavier rail than is absolutely necessary to carry the weight. For general mining purposes the weight per yard is usually from 14 to 16 lb.

The following table will give an approximate idea of the weight of rails, gauge of line, load, and cost per yard of railway all complete ready for laying, with steel flange rails, patent steel sleepers, fished joints, made up in 5-yd. lengths with sleepers 3 ft. apart.

	Approximate Load per Axle.	Price per yard of Railway.
		s. *d.*
Rails 9 lb. per yard for 18-in. gauge tramway .	1000 lb. .	2 4
,, 12 ,, ,, 18 ,, ,, ,, .	1500 ,, .	2 9
,, 16 ,, ,, 20 ,, ,, ,, .	2 ton .	3 5
,, 16 ,, ,, 24 ,, ,, ,, .	2 ,, .	3 6
,, 24 ,, ,, 30 ,, ,, ,, .	4 ,, .	4 11

For permanent light railways with passenger and goods traffic worked by locomotives, often laid as feeders to a main line system, and for the transport of the material to and from a group of mines or mining district, the metre gauge with rails weighing from 40 to 50 lb. per yard is now widely established.

Sleepers.—In countries where there is an abundance of wood this material is employed for sleepers, but of late years metallic sleepers made of sheet steel have come into general use. Messrs. J. and F. Howard, of Bedford, who are makers of portable railway plant for mining and other purposes, have adopted the form of sleeper shown in figs. 366 and 367. The sleeper is made of plate steel corrugated and flanged in order to give the greatest strength with the least weight of material. The chairs for the rails are formed by pressure on the crown of the sleeper, none of the metal being cut away, but, on the contrary, those parts of the chairs upon which the rails rest are increased in thickness and durability, and as the chairs are made by special hydraulic machinery the exact gauge of the line is always maintained. The rail thus rests upon the whole width of the sleeper, giving great bearing surface. No bolts, dogs, or rivets are required, the only fastening being the simple metal key shown in the drawing, and this is serrated on one side to fit into the cheeks of the chair when driven home. For underground work a modified form of sleeper is used which can be threaded on to the rails and the keys thus dispensed with.

The method of laying the line is shown in fig. 356. The jointing sleepers are formed in the same manner as the single sleepers, except

that two corrugations are rolled on one plate; the chairs or rail seats are pressed out of each corrugation in such a manner that the rail ends abut and are held in each seating respectively by its own serrated key. The keys are so arranged that either of them may be taken out without

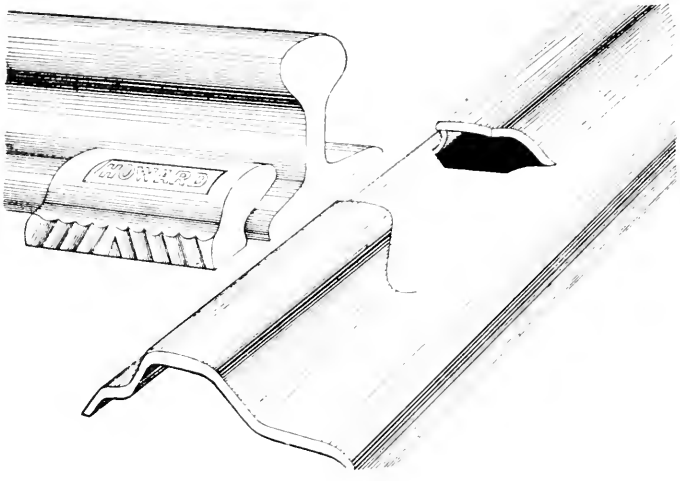


Fig. 366.—Steel Sleeper, Key, and Rail for Portable Railway.

disturbing the others. This method of fastening and joining the lengths of rails, enables the laying down, and also the removing of the road to be effected with the greatest ease and despatch.

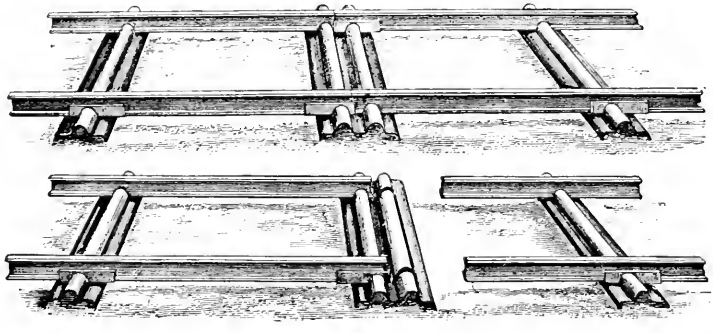


Fig. 367.—Portable Railway, showing Jointing Sleepers.

The corrugated form of sleeper allows the ballast to set down very firm under the sleeper, and the rail seats being below the crown of the sleeper, prevent any tendency of the sleeper to shift sideways on curves. For animal power lines this is the strongest form of sleeper, as the corrugation prevents any bending likely to be caused by the constant

treading of the animals employed, and also gives a good foothold, thus preventing the slipping so frequent on flat-crowned ground.

The advantages of a portable line of rails of this form may be summed up as follows:

Simplicity, strength, and durability.

Accuracy of gauge, which cannot vary, as the seats for the rails are formed by special machinery.

The gauge does not depend on the skill of the workman, and will be preserved as long as the line lasts.

No bolts, rivets, or spikes, with their many disadvantages, are required to fasten the rails to the sleepers.

A metal *safety key* fastens the rail to the steel sleeper, so that it cannot shake loose.

The rails may be laid down, removed, and relaid in the most expeditious manner, without skilled labour.

The rails and sleepers, not being riveted together, stow into small space, whereby cost of freight is reduced to a minimum.

In order to prevent corrosion, the patent sleepers are coated with an anti-oxidation compound, while for handling and shipment there is no fear of any damage to the sleeper or alteration in shape, nor are there any projections to break off. They are shipped ready for laying, a great consideration where skilled labour is scarce.

The suitability of various lines depends largely upon the weight of the locomotive to be used, the traffic over the line, and the loads to be carried. The attention given to the laying and ballasting of the road has a great influence upon the resistance of the line to the load. The wear and tear upon the railway, as well as the rolling stock, increases considerably as the load approaches the maximum carrying power of the line, and although such a line is cheaper in first cost, it will be found far more expensive for subsequent maintenance and renewals than a heavier railway, the strength of which is well beyond the maximum loads and traffic it has to carry.

On lines of a semi-permanent character where locomotives are used, the employment of the jointing sleeper, so advantageous on a portable railway, becomes unnecessary. Hence it is usually preferred to lay such lines with the ordinary suspended fish joint, similar to that in general use upon main lines. The rigidity of the line is maintained, and the jointing sleeper is dispensed with.

For light locomotives suitable sleepers should be placed 3 ft. from centre to centre. For heavier traffic stronger sleepers are recommended to be placed 2 ft. 9 in. from centre to centre.

In the setting out of a light permanent line, too much care cannot be bestowed upon the preparation of the road, as this will be amply repaid by the saving in the subsequent cost of working the line. Before

fixing upon the route to be followed, a rough survey is advisable, avoiding as far as possible heavy gradients and sharp curves. Careful attention to the ballasting of the sleepers will render the travelling easier and the working expenditure less, while heavier loads can be carried. Sharp curves entail great wear and tear on the line and rolling stock.

For semi-portable lines less attention is paid to the laying and ballasting of the line, and therefore the same load cannot be carried on these as on well-ballasted, light permanent lines of the same weight.

For lines worked with locomotives either 1760 or 1920 steel sleepers are supplied for each mile of railway according to the work. For permanent light lines worked with locomotives, the steel sleepers should be spaced 2 ft. 9 in. from centre to centre, that is, 1920 sleepers to each mile of railway.

The rails are supplied in lengths up to 21 ft., and of various sections according to the nature of the traffic.

The usual gauges for these lines are as under :

With Rails per yard.	Gauges.	With Sleepers.	Approximate average weight with sleepers, keys and fish-plates per mile.	Length of sleeper over and above the gauge.
14 lb.	20 in., 24 in., 500 mm., 600 mm., 30 in., 36 in., 750 mm., 900 mm., metre	1760 No. 4	34 tons	12 in.
16 lb.	20 in., 24 in., 500 mm., 600 mm., 30 in., 36 in., 750 mm,, 900 mm., metre	1760 No. 4	37 tons	12 in.
18 lb.	24 in., 30 in., 600 mm., 750 mm., 36 in., 900 mm. metre	1760 No. 4	41 tons	12 or 18 in., according to the work.
22 lb.	24 in., 30 in., 600 mm., 750 mm., 36 in., 900 mm. metre	1920 No. 2	53 tons	18 or 24 in., according to the work.
26 lb.	30 in., 36 in., 750 mm., 900 mm., metre	1920 No. 2 1920 No. 3	61 tons 64 tons	18 or 24 in., according to the work.
40 lb.	36 in., 900 mm. metre	1920 No. 7	105 tons	24 in.

Points and Crossings.—For shunting purposes underground, on the pit bank or in the mill, especially if the wheels run loose on their axles, it is customary to employ a square cast or wrought iron plate upon which

the tram waggon can be twisted in any direction. For permanent outside work, and also on the main roads underground, properly designed points and crossings, such as those shown in figs. 368 to 371 must be used.

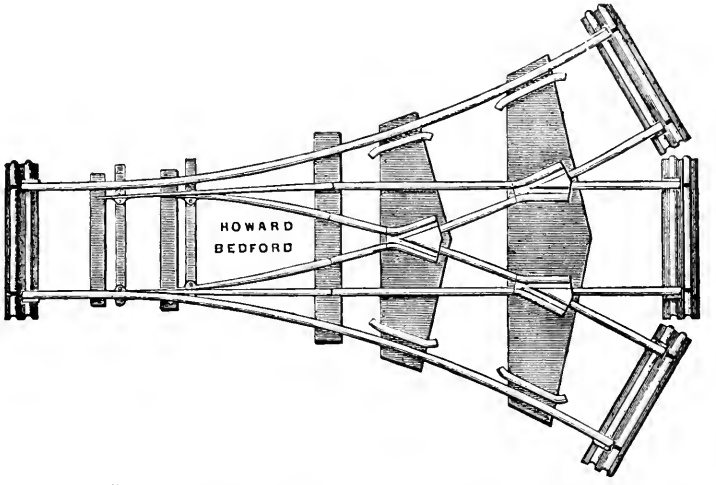


Fig. 368.—Three-Way Points for Portable Railway.

Fig. 368 is a three-way, fig. 369 a right-hand, and fig. 370 a left-hand set of points and crossings, while fig. 371 shows the arrangement of a siding.

The sidings are formed, as shown in the illustration, by a set of points

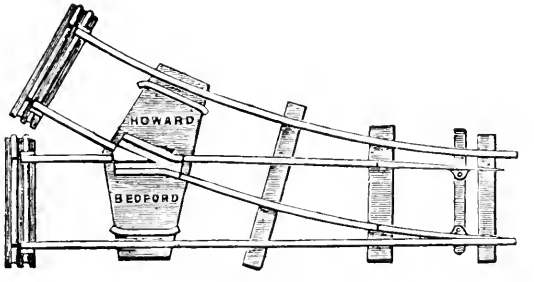


Fig. 369.—Right-Hand Points for Portable Railway.

and crossings, either right or left hand, a section of curved line, and a number of sections of right line.

Pass-bys in a straight line are made by a pair of right- and left-hand points and crossings, with two curved pieces and the desired length of line between. These pass-bys are necessary on lines of any considerable length, and especially where many waggons are in use.

For special curves, which must be shaped on the spot, an ordinary rail bender, called a "Jim Crow," is required.

The points are made with movable tongues or switches connected together by a cross bar. For locomotive-power lines the points are provided with levers and switch boxes; but for animal-power lines, levers, and switch boxes are not usually considered necessary. For

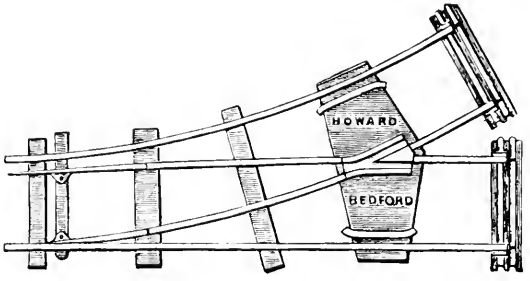


FIG. 370.—LEFT-HAND POINTS FOR PORTABLE RAILWAY.

locomotive traffic the points and crossings can be provided with a signal disc or lantern.

The single set either right hand or left hand may be so contrived, that by taking a pair of rails from any part of the straight line, the points and crossings will take the place of the removed section of rails without cutting or fitting, and this removal can be quickly effected.

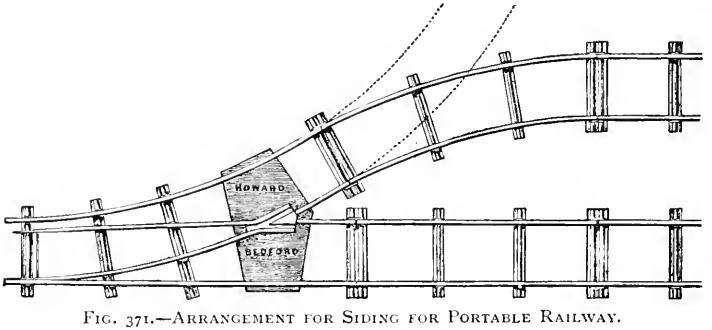


FIG. 371.—ARRANGEMENT FOR SIDING FOR PORTABLE RAILWAY.

As a general rule, when setting out a line, it is better to arrange for single sets of points as far as possible, for the wear and tear on two single sets of points will be found very much less than on one set of double points, and there is the further advantage of simplicity in laying down and keeping the line in order.

For the successful working of portable railways it is very important that the points and crossings should be accurately made, and so constructed that they cannot easily get out of form by the wear and tear of traffic.

The points and crossings are made of standard sizes with curves of 20, 25, and 30 ft. radius, and, where locomotives are used, they are made with curves of 100 ft. radius, or to any special radius required to suit the gauge of the rails and the wheel base of the engines. For locomotives of the main line of tram the curves should not, as a rule, have a radius of less than 150 to 200 ft.

When the tram and load is too heavy to be turned on a plain plate some form of turntable becomes necessary. It should, however, be remembered, in laying down a plant, that wherever curves and points can be used instead of a turntable, the advantages of the curve are considerable, and, except in very confined positions, a curve can generally

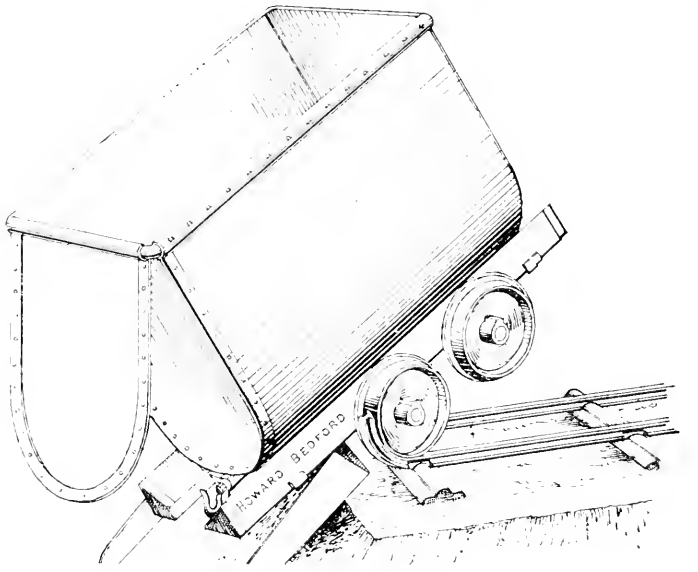


Fig. 372.—Tipping Waggon.

be adopted. A train of waggons will pass a curve in less time than a single truck can be turned on a table. There are, however, positions where turntables are indispensable.

Tram Waggons.—The older forms of tram waggons for mining purposes were constructed chiefly of wood, which was rapidly destroyed by the rough usage to which of necessity the trunks were subjected. The type now commonly in use is shown in fig. 372.

The tub is made of steel plate with one flanged end firmly riveted in, the other end being formed by a flap door hinged at the top on a round bar, which is in one piece with the riveted half-round top beading. This top beading is a solid welded ring, and holds the body rigidly

together. By this means the manifold advantages of a solid top beading are secured, whilst a simple hinged door is obtained. The lever catch fastening the door passes under the tub, and is worked from the rear of the waggon, and a through drawbar is provided.

The tub is mounted on an oak under-frame, the ends being shod with wrought iron and the wheels are placed close together and slightly to the rear of the waggon, thus ensuring an easy tip.

If desired the ends of the oak under-frame can be fitted with special buffers ; and if required the wheels and axles are fitted up with a fiddle-frame, so that the hind pair of wheels do not leave the rails. The axles and wheels are of steel.

The usual sizes of these waggons are 10 cubic ft. and 16 cubic ft. capacity.

Tipping waggons are constructed in various forms to suit the purpose for which they are to be used, such as the single end tip, the double side tip, and the all-round tip waggon ; the general construction is the same, but is so arranged that the load may be discharged as described.

The tip waggons are made with steel tubs, carried upon two pairs of wrought iron trunnions. These trunnions are firmly riveted through the end plate of the tub, which is strengthened by an additional inside and outside trunnion plate. The tub ends are flanged by hydraulic machinery, and are riveted firmly to the sides, which are of one plate. A strong half-round welded ring is riveted round the top of the tub, and holds it rigidly together. By this method of construction a very strong and durable tub is obtained. The under-frame is of channel steel, with steel bowed buffer ends, and steel angle stays across the under-frame ; the draw gear is attached to a through stay ; the axles are of steel and the wheels of chilled iron or cast steel. Waggons with round buffer ends are far superior for light railway work to those built with corner buffers, as the liability to derailment on curves is greatly lessened. The trunnions are placed at such a distance apart as to ensure steady running, thus dispensing with safety chains whilst still maintaining an easy tip. In some sizes of waggons four pairs of trunnions are employed to ensure a good tip.

The tubs which lift off the under-frame can be supplied with two stout rings to receive hooks from chains at the end of a winding rope. The body of the waggon, with its load of ore, can thus be wound up the shaft and dropped on to another frame at the surface; or it can be transported, with its load, by an aerial tram placed on a fresh framework at the end of its journey, thus avoiding the carriage of useless weight.

For mining purposes the double side-tipping waggon, shown in fig 373, is largely used.

The special form of the tub admits of large capacity without great width, and allows the waggon to pass through narrow drives. It is also

very suitable for work on the surface. By the use of four pairs of trunnions a large tipping angle is obtained, the material thus emptying freely.

The general construction of the waggon is similar to the other forms of tip waggons. The under-frames are of channel steel and the trunnion supports of angle steel.

The drawbar passes throughout the length of the under-frame, forming a central stay.

The waggons are fitted with axle boxes, steel axles, and chilled iron or steel wheels.

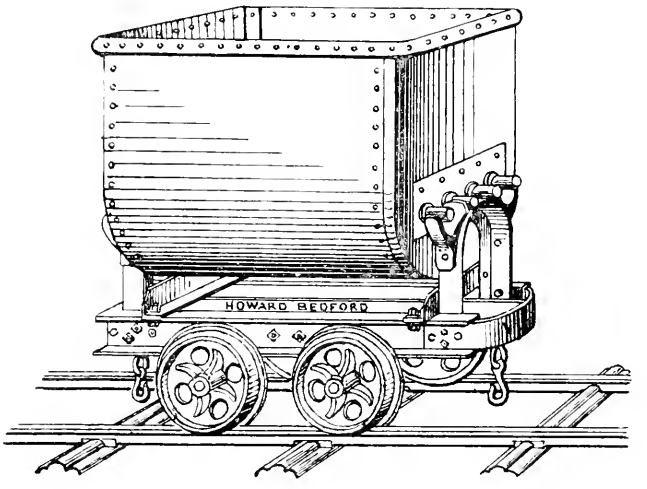


Fig. 373.—Double Side-tipping Waggon.

The usual sizes of these waggons are 10 cubic ft., and 16 cubic ft. capacity on a guage of 18 in. to 24 in.

For the purpose of controlling and ascertaining the daily output of the mine the waggons should be weighed, and their weight painted on the side.

Before entering the mill the loaded waggons should all be weighed, and the net weight of the ore entered in a book kept for that purpose. This weighing of the crude ore, taken in conjunction with the sampling under the rock-breaker, will give the daily value of the ore treated, while the weight and assay of the concentrated ore will give that of the output of the mill.

The difference between the two will be the amount of loss in treatment, and to this little difference the manager cannot pay too much attention.

Traction Engines.— The use of the traction engine forms the last link in the chain of transport by road which commences with panniers on mule-back, is followed on by all sorts of wheeled vehicles drawn by bullock- or horse-power, and ends with these road locomotives, which, in many parts of our own country—in Wales and Cornwall—and in different foreign countries, are employed to haul the produce of the mines and quarries to the nearest railway station or shipping port. Their use, however, implies the existence of a tolerably good hard road, with bridges and culverts sufficiently strong to carry their weight, and a highway-board not too exacting in the matter of rates. In England the use of traction engine on the public roads has of late years largely increased, and the restrictions are not now so great as formerly; while horses, which at

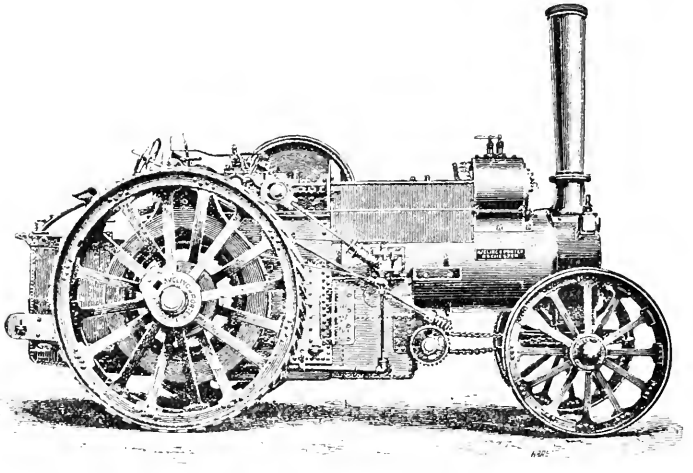


Fig. 374.—Traction Engine.

one time were very nervous when meeting them, have become more or less used to their appearance as well as that of the motor-cars.

The engines have considerable hill-climbing power, and can drive themselves up any hill that a horse and waggon could surmount; but for practical purposes it may be laid down that ingradients greater than 1 in 12 cannot be economically worked, and that up these the engine will haul a load equal to twice its own weight.

The most improved form of traction engine, as made by Messrs. Aveling & Porter, of Rochester, is shown in fig. 374, and the type of waggon manufactured by the same firm for use with these engines is shown in fig. 375.

The engine boiler and fire-box are made of the best quality steel or Yorkshire iron plates, and the boiler itself is tested by hydraulic pressure to 250 lb. per square inch.

Up to within recent years it was the universal practice to mount the principal working parts of these engines on cast or wrought iron brackets bolted to the boiler, and the strain thrown on the boiler by the unequal working of the crankshaft, countershaft, and driving axle always manifested itself sooner or later in leakage at the numerous bolt holes and in corresponding corrosion of the boiler plates. In order to obviate this difficulty Messrs. Aveling & Porter patented the arrangement of brackets since fitted to all their engines, which entirely overcame these evils, and at the same time provides more stable and convenient bearings than under the usual system of construction. By prolonging the side plates of the fire-box upwards, perfect brackets are formed without the necessity of bolting them to the boiler; and these brackets are so shaped as to carry

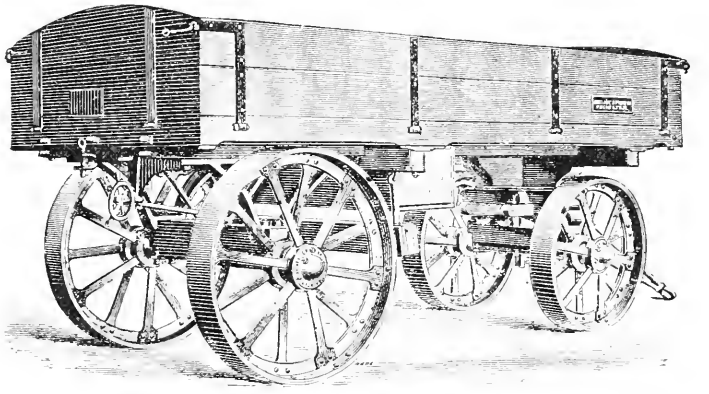


Fig. 375.—Waggon for Traction Engine.

the bearings of the crankshaft, countershaft, and driving axle, and, therefore, to effectually relieve the boiler from their strain.

Another improvement has also been effected. Hitherto the gearing of road locomotives has been placed outside the crank and countershaft brackets; but by the new arrangement of gearing the wheels and pinions are fixed to their respective shafts between (not outside) the bearings, and the driving-wheels as well as flywheel are brought up close to the side-plate brackets. The engine is stronger, narrower, more compact in consequence, and its wear and tear most substantially reduced. The flywheel is fixed close to the crankshaft bearings. The engine is geared for two speeds and the pinions for these two speeds are keyed fast upon the crank-shaft instead of sliding upon feathers. The intermediate shaft is fixed and serves as a stay to the side plates, and the sliding sleeve which carries the spur-wheel and the fast- and low-speed pinions, revolves on it. The axle, crankshaft and countershafts are of steel. The gearing is all of the best crucible steel, and the teeth are shrouded.

The driving wheels are of large diameter and width, and are fitted with compensatory motion for turning sharp curves without disconnecting either wheel. The engine is steered from the foot-plate by means of the hand-wheel shown in the illustration.

Each engine is supplied with water elevator and 26 ft. of india-rubber hose, steam pressure-gauge, and extra safety-valve, a complete set of wrenches, caulking tool, tube brush and rod, lead rivets, screw-hammer, firing-tools, oil-feeder, spare gauge-glasses, driving-wheel studs or paddles, lamps, screw-jack, hammer, chisel, oil-can, water-funnel, pails, and water-proof cover.

The working expenses, including wear and tear with interest on capital, vary from $1\frac{1}{4}d.$ per ton per mile for continuous work under favourable conditions of road and load to $3d.$ per ton per mile for short distances with return journey unloaded.

The waggons, as shown in fig. 375, are made to carry from 4 to 6 tons each, and are fitted with wrought iron wheels and oil boxes. The wheels have double tyres 6 in. and 8 in. wide. The sides and ends can be let down for unloading, or the waggons can be built to tip sideways. The couplings are arranged so that the train will turn any curve, however sharp, each waggon following in the track of the preceding one. The drawbars are fitted with coiled springs to relieve the engine from shocks when starting with a heavy load. The front axles are made shorter than those of the hind wheels, so that the wheels do not track, and the roads are saved unnecessary wear and tear.

The prices of traction engines and waggons vary greatly with the fluctuations in the price of metal, so that the following list of these machines, as made by Messrs. Aveling & Porter must be taken as approximate only:

ROAD LOCOMOTIVES OR TRACTION ENGINES.

Nominal Horse-power	6	8	10
	£	£	£
Price, with fittings as per catalogue	495	560	630
Extra if made compound	55	75	100
Colonial fire-box for burning wood, etc.	10	10	10
Packing for long sea voyage	10	15	20

WAGGONS.

To carry	4 tons.	6 tons.
	£	£
Price with wrought iron wheels and spring drawbar	60	70
Springs	10	10
Friction brake	3	3

Steam Lorries.—Since the first edition of this work was published the regulations relative to steam traffic on the public roads have been greatly modified by the Act of 1896; and as a consequence the attention of manufacturing firms has been turned to the design, of heavy steam waggons or lorries for the transport of goods and mining material.

The general type of such waggons made by the Thorneycroft Steam Waggon Company, of Chiswick and Basingstoke, is illustrated in fig. 376.

Their standard heavy waggon carries 3 tons, and hauls a further 2 to 3 tons on a trailing vehicle when required; the legal limit of speed—5 miles an hour—is maintained with the greatest ease in all weathers.

A daily mileage of 35 to 40 can be relied on 5 days per week, or 260 days a year.

Welsh coal, coke, or oil can be used as fuel; sufficient is carried for a full load run of 40 to 50 miles; water for 15 to 20 miles is also carried. No smoke or steam is visible when running.

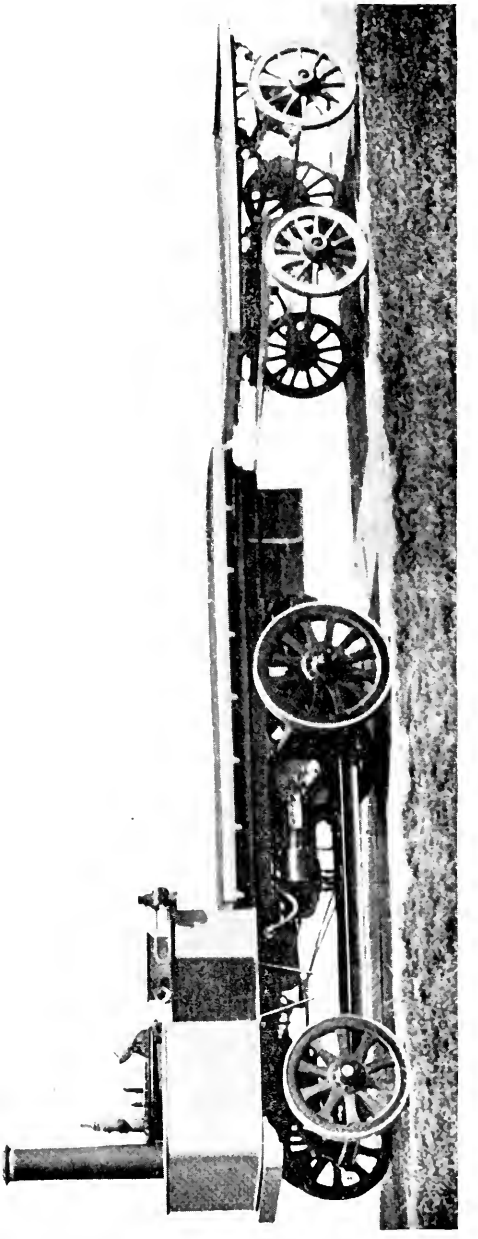


Fig. 376.—Steam Lorry.

The total cost of carrying one ton one mile, inclusive of depreciation, interest, wages, fuel, adjustments and repairs, and stores is stated to be from $2\frac{1}{2}d.$ to $3\frac{1}{2}d.$

The divided-axle method of steering is adopted, the leading wheels being moved by a large hand-wheel in front of the driver, through the medium of a worm and sector; the steering-gear is thus self-locking in all positions. The front axle is further mounted upon a pivot at its centre, and the vehicle is therefore supported upon these points, viz., the two axle-boxes of rear axle, and the pivot of the front axle; the channel-steel under-frame is in this way relieved from much transverse twisting action.

The platform is of the usual Liverpool lorry type, surrounded by a low steel rim; iron stanchions, with connecting chains, can also be mounted when required. The length of platform is 15 ft. $1\frac{1}{2}$ in., and width 6 ft. $5\frac{1}{4}$ in.; the level carrying area is therefore $97\frac{1}{2}$ square ft. This platform is of very substantial construction, of oak and steel, and will withstand continuous rough usage. The under-frame is of deep channel-section steel, suitably strengthened by transverse members and gussets, and provides a rigid support for the boiler, engine, and transmission gear; the carrying platform is simply attached to this frame by a few bolts, and may be readily replaced by a body of any other type in the manner common to all the vehicles of this company.

The boiler of the Thorneycroft straight-water-tube type is central-fired from the top, and constructed to burn ordinary gas coke as fuel. A large heating surface and grate area are provided, in order to give ample steaming power under all circumstances. The boiler is wholly of steel, and is inspected, tested, and guaranteed by the Manchester Steam Users' Association; it is placed in the centre of front of vehicle, and all mountings are so arranged as to be easily under control of the driver, and in full view. The fire is regulated by a door in ashpan, and by the cover on firing hove; due to the large volume of fire-box, it is only necessary to supply fuel about once in threequarters of an hour when running in ordinary daily service.

Two safety-valves are fitted, of which one lifts if the normal working pressure be exceeded, while the other is set at 10 lb. per square inch above normal pressure, and rises in the event of the first failing to act. The water gauge is of the unbreakable "reflex" pattern, and is in full view of the driver while seated; all mountings are so designed as to be readily cleansed from deposit. While running, the boiler is fed by a pump driven directly by the engine; when stationary, the engine may be disconnected from the transmission gear, and run free, thus feeding boiler; or the feed-water may be supplied by an injector of special pattern, mounted on the boiler itself. This injector is so designed that the cones may be withdrawn for examination and cleaning while under steam.

The feed-water supplied by the engine pump passes through an exhaust steam feed heater, thus economising fuel.

Suitable plugs are fitted in the bottom of boiler for draining and cleaning out; a blow-off cock is also fitted. The fire is cleaned through a special "clinkering hole," easily accessible from near side of vehicle. The water tubes are cleaned by removing the top cover of boiler and passing a steel wire brush through each; this should be done once weekly, and occupies altogether about three hours. The soot on the outside of tubes is removed by taking off the sides of the boiler casing (which has been expressly designed to permit this being rapidly done), and directing a dry steam-jet upon them; a suitable steam hose, nozzle, and attachment is provided for this purpose.

The engine is horizontal, compound, reversing, having cylinders 4 in. and 7 in. in diameter × 5 in. stroke, and fitted with a special design of constant lead radial valve gear, permitting of any degree of "linking-up." The engine is completely enclosed in a dustproof and oil-tight casing, and the lubrication is on the splash method. Though wholly enclosed, all parts are readily accessible for examination or adjustment. The engine is capable of running for long periods at 800 revolutions per minute, and with 200 lb. steam pressure will indicate up to 35 horse-power. The exhaust steam passes through a feed heater, whereby the boiler feed-water is raised to a high temperature, and fuel is economised; the exhaust thence passes into the smoke-box, whence it mingles with the flue gases, and is discharged invisibly from the funnel; a spark-arrester is fitted in the smoke-box through which all the flue gases are drawn by the draught created by the exhaust steam.

The bunkers have a capacity of 38 cubic ft., and will contain sufficient coke to carry the fully loaded vehicle 50 miles. The feed tank is suspended from the under-frame at the rear end of vehicle, and contains sufficient water for a full load run of 18 or 23 miles. A steam water lifter is fitted on the feed tank, and a length of hose provided by which means the tank may be replenished from any source available on the route in about 5 minutes.

A powerful screw-down brake is fitted, whereby wooden blocks are applied to each rear tyre. The reversal of the engine also provides a second ready and effective breaking action.

A steam start is fitted for accelerating the raising of steam. A by-pass valve is also available for admitting full boiler pressure to the low-pressure cylinder when occasion demands, and the vehicle is fitted with a draw hook for the attachment of the trailer.

The transmission is chainless. Two machine-cut pinions ride upon a square part formed on the engine crank-shaft, either of which may be armed to gear with machine-cut spur wheels on the first part of countershaft; giving thus the normal and belt-climbing gears respectively.

The countershaft is in three pieces, connected by special universal joints and other devices in order to obtain a mechanically perfect transmission; and the rear wheels are driven through the Thorneycroft spring drive consisting of small helical springs in compression.

Vehicles of the above type are now commonly seen on the high roads in the manufacturing districts; and it would seem that they could be advantageously employed in the transport of mineral and mining material in all localities where the roads are tolerably good.

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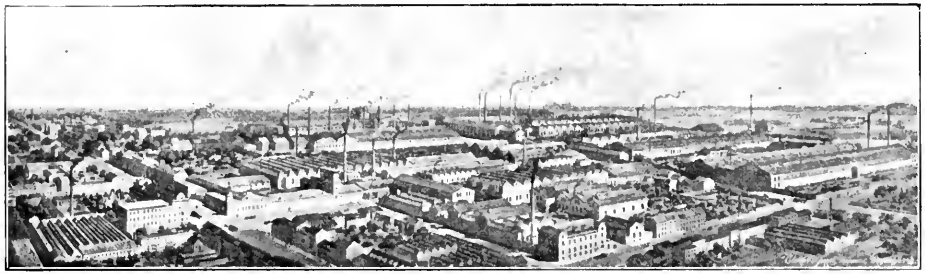

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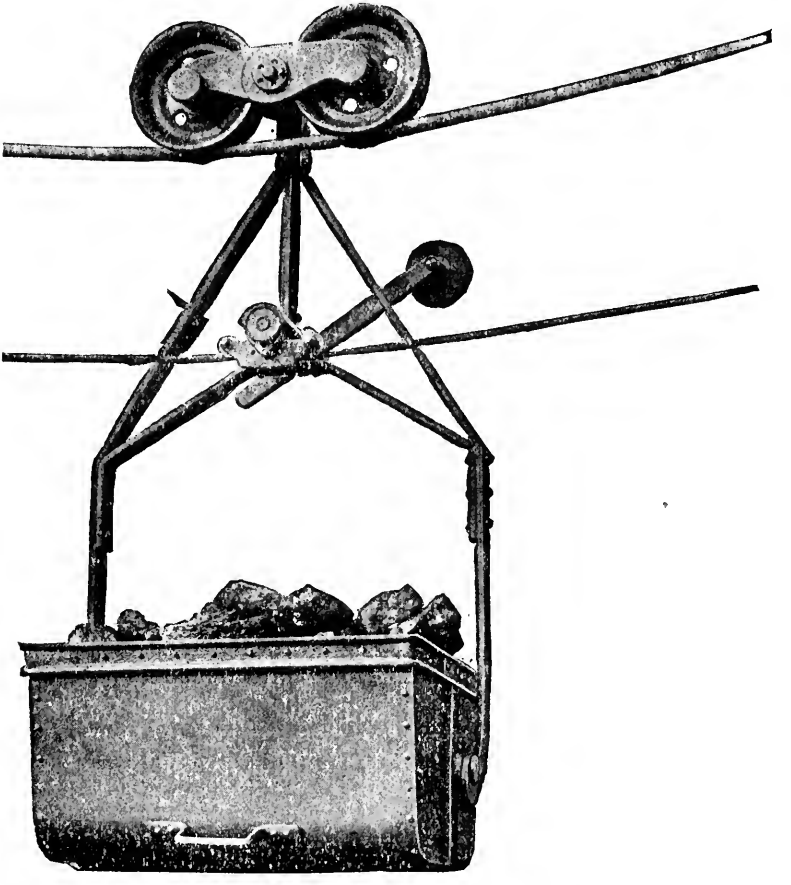

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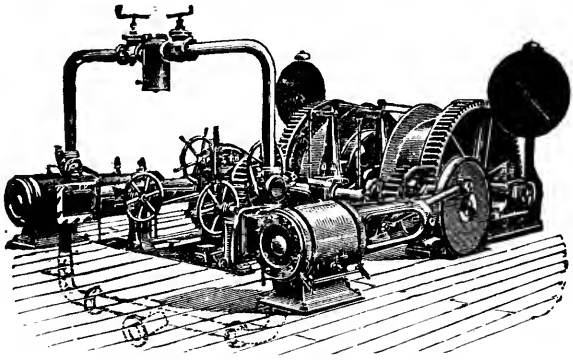

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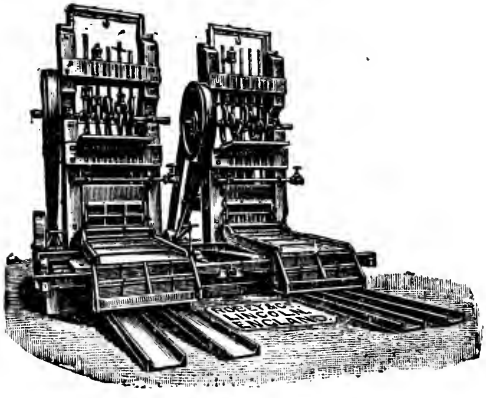

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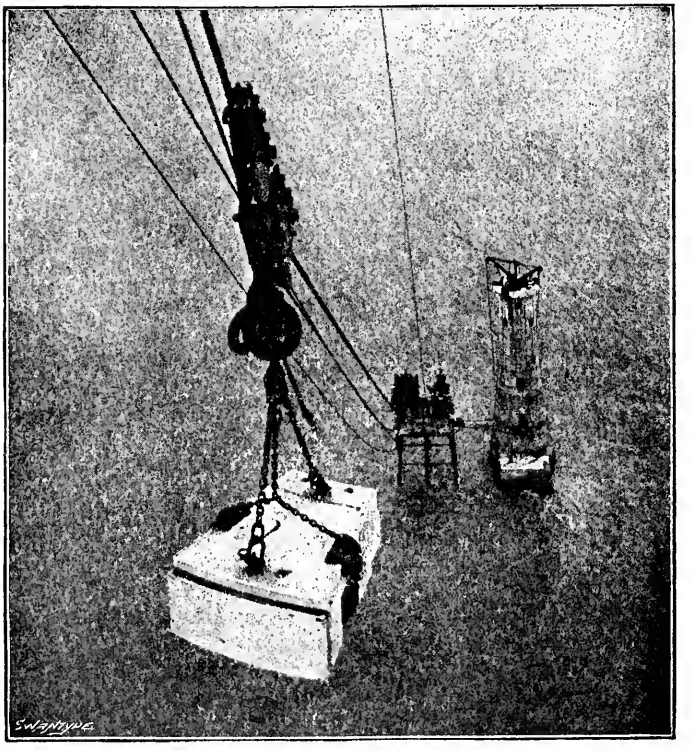

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